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Ford IBM RCA

SPACE STATION DATA SYSTEM ANALYSIS/ARCHITECTURE STUDY

Task 3 – Trade Studies, DR-5
Volume I

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MCDONNELL DOUGLAS CORPORATION

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HUNTINGTON BEACH

5301 Bolsa Avenue Huntington Beach, California 92647 (714) 896-3311

PREFACE

The McDonnell Douglas Astronautics Company has been engaged in a Space Station Data System Analysis/Architecture Study for the National Aeronautics and Space Administration, Goddard Space Flight Center. This study, which emphasizes a system engineering design for a complete, end-to-end data system, is divided into six tasks:

Task 1. Functional Requirements Definition
Task 2. Options Development
Task 3. Trade Studies
Task 4. System Definition
Task 5. Program Plan
Task 6. Study Maintenance

This report contains the results of Task 3. Trade Studies resulting from Options Development (Task 2) were performed to aid in System Definition (Task 4).

McDonnell Douglas was assisted in Task 1 by the Ford Aerospace and Communications Corporation, IBM Federal Systems Division and RCA Government Systems Division.

This report was prepared for the National Aeronautics and Space Administration Goddard Space Flight Center under Contract No NAS5-28082 as a part of Task 3 activities.

Questions regarding this report should be directed to:

Glen P. Love
Study Manager
McDonnell Douglas Astronautics Company
Huntington Beach, CA 92647
(714) 896-2292

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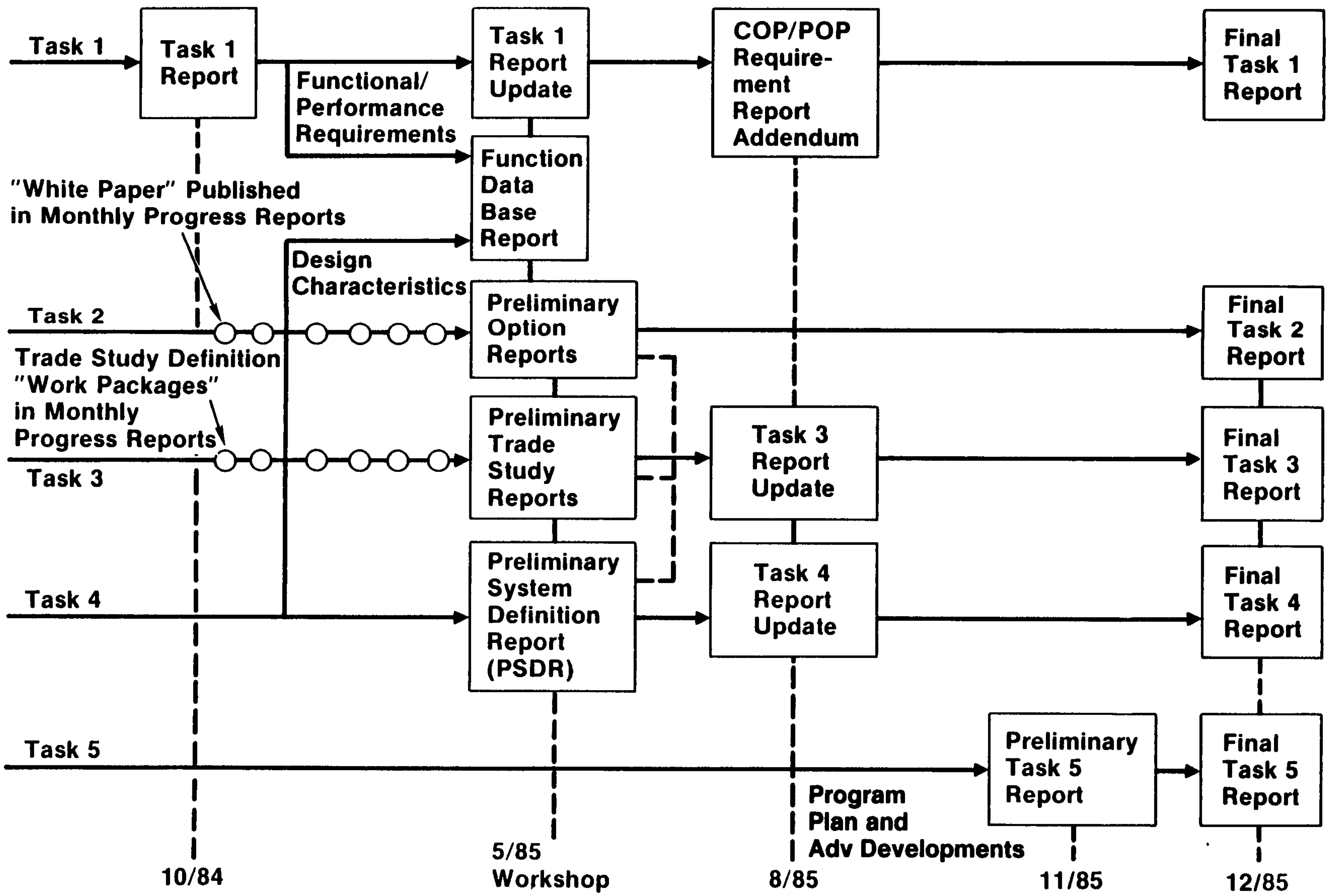
SSDS A/A DOCUMENTATION SCHEDULE



CONTENTS
TASK 3 VOLUME I

GLOSSARY

A	Automatic
A&R	Automation and Robotics
A/A	Analysis/Architecture
A/D	Advanced Development
A/L	Airlock
A/N	Alphanumeric
AC&S	Attitude Control System
ACA	Attitude Control Assembly
ACO	Administrative Contracting Officer
ACS	Attitude Control and Stabilization
ACS/COM	Attitude Control System/Communications
ACTS	Advanced Communications Technology Satellite
AD	Ancillary Data
AD	Advanced Development
ADOP	Advanced Distributed Onboard Processor
ADP	Advanced Development Plan
AFOSR	Air Force Office of Scientific Research
AFP	Advanced Flexible Processor
AFRPL	Air Force Rocket Propulsion Laboratory
AGC	Automatic Gain Control
AGE	Attempt to Generalize
AI	Artificial Intelligence
AIE	Ada Integrated Environment
AIPS	Advanced Information Processing System
AL1	Air Lock One
ALS	Alternate Landing Site
ALS/N	Ada Language System/Navy
AMIC	Automated Management Information Center
ANSI	American National Standards Institute
AOS	Acquisition of Signal
AP	Automatic Programming
APD	Avalanche Photo Diode
APSE	Ada Programming Support Environment
ARC	Ames Research Center

ART	Automated Reasoning Tool
ASCII	American Standard Code for Information Exchange
ASE	Airborne Support Equipment
ASTROS	Advanced Star/Target Reference Optical Sensor
ATAC	Advanced Technology Advisory Committee
ATC	Air Traffic Control
ATP	Authority to Proceed
ATPS	Advanced Telemetry Processing System
ATS	Assembly Truss and Structure
AVMI	Automated Visual Maintenance Information
AWSI	Adoptive Wafer Scale Integration
B	Bridge
BARC	Block Adaptive Rate Controlled
BB	Breadboard
BER	Bit Error Rate
BIT	Built-in Test
BITE	Built-in Test Equipment
BIU	Buffer Interface Unit
BIU	Bus Interface Unit
BIU	Built-in Unit
BMD	Ballistic Missile Defense
BTU	British Thermal Unit
BW	Bandwidth
C	Constrained
C^2	Command and Control
C^3	Command, Control, and Communication
C^3I	Command, Control, Communication, and Intelligence
C&DH	Communications and Data Handling
C&T	Communication and Tracking Subsystem
C&T	Communications and Tracking
C&W	Control and Warning
C/L	Checklist
CA	Customer Accommodation
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAIS	Common APSE Interface Set
CAM	Computer-Aided Manufacturing

CAMAC	Computer Automatic Measurement and Control
CAP	Crew Activities Plan
CASB	Cost Accounting Standard Board
CASE	Common Application Service Elements
CATL	Controlled Aceptance Test Library
CBD	Commerce Business Daily
CBEMA	Computer and Business Equipment Manufacturing Association
CCA	Cluster Coding Algorithm
CCB	Contractor Control Board
CCB	Configuration Control Board
CCC	Change and Configuration Control
CCD	Charge-Coupled Device
CCITT	Consultive Committee for International Telegraph and Telephone
CCITT	Coordinating Committee for International Telephony and Telegraphy
CCMS	Checkout Control and Monitor System
CCR	Configuration Change Request
CCSDS	Consultative Committee for Space Data System
CCTV	Closed-Circuit Television
cd/M^2	Candelas per square Meter
CDG	Concept Development Group
CDMA	Code Division Multiple Access
CDOS	Customer Data Operations System
CDR	Critical Design Review
CDS	Control Data Subsystem
CE	Conducted Emission
CEI	Contract End-Item
CER	Cost Estimating Relationship
CFR	Code of Federal Regulations
CFS	Cambridge File Server
CG	Center of Gravity
CIE	Customer Interface Element
CIL	Critical Item List
CIU	Customer Interface Unit
CLAN	Core Local Area Network
CM	Configuration Management
CM	Center of Mass
CMDB	Configuration Management Data Base

CMG	Control Moment Gyro
CMOS	Complementary Metal-Oxide Semiconductor
CMS	Customer Mission Specialist
CMU	Carnegie-Mellon University
CO	Contracting Officer
COF	Component Origination Form
COL	Controlled Operations Library
COMM	Commercial Missions
COP	Co-orbital Platform
COPCC	Coorbit Platform Control Center
COPOCC	COP Operations Control Center
COTS	Commercial Off-the-Shelf Software
CPCI	Computer Program Configuration Item
CPU	Central Processing Unit
CQL	Channel Queue Limit
CR	Compression Ratio
CR	Change Request
CR&D	Contract Research and Development
CRC	Cyclic Redundancy Checks
CRF	Change Request Form
CRSS	Customer Requirements for Standard Services
CRT	Cathode Ray Tube
CS	Conducted Susceptibility
CSD	Contract Start Date
CSDL	Charles Stark Draper Laboratory
CSMA/CD/TS	Carrier-Sense Multiple with Access/Collision Detection and Time Slots
CSTL	Controlled System Test Library
CTA	Computer Technology Associates
CTE	Coefficient of Thermal Expansion
CUI	Common Usage Item
CVSD	Code Variable Slope Delta (Modulation)
CWG	Commonality Working Group
D&B	Docking and Berthing
DADS	Digital Audio Distribution System
DAIS	Digital Avionics Integration System
DAR	Defense Acquisition Regulation

DARPA	Defense Advanced Research Projects Agency
DB	Data Base
DBA	Data Base Administrator
DBML	Data Base Manipulation Language
DBMS	Data Base Management System
DCAS	Defense Contract Administrative Services
DCDS	Distributed Computer Design System
DCR	Data Change Request
DDBM	Distributed Data Base Management
DDC	Discipline Data Center
DDT&E	Design, Development, Testing, and Engineering
DEC	Digital Equipment Corp.
DES	Data Encryption Standard
DFD	Data Flow Diagram
DGE	Display Generation Equipment
DHC	Data Handling Center
DID	Data Item Description
DIF	Data Interchange Format
DMA	Direct Memory Access
DMS	Data Management System
DoD	Department of Defense
DOMSAT	Domestic Communications Satellite System
DOS	Distributed Operating System
DOT	Department of Transportation
DPCM	Differential Pulse Code Modulation
DPS	Data Processing System
DR	Discrepancy Report
DR	Data Requirement
DRAM	Dynamic Random-Access Memory
DRD	Design Requirement Document
DS&T	Development Simulation and Training
DSDB	Distributed System Data Base
DSDL	Data Storage Description Language
DSDS	Data System Dynamic Simulation
DSIT	Development, Simulation, Integration and Training
DSN	Deep-Space Network
DTC	Design to Cost

DTC/LCC	Design to Cost/Life Cycle Cost
DTG	Design To Grow
E/R	Entity/Relationship
EADI	Electronic Attitude Direction Indicator
ECC	Error Correction Codes
ECLSS	Environmental Control and Life-Support System
ECMA	European Computers Manufacturing Assoc.
ECP	Engineering Change Proposals
ECS	Environmental Control System
EDF	Engineering Data Function
EEE	Electrical, Electronic, and Electromechanical
EHF	Extremely High Frequency
EHSI	Electronic Horizontal Situation Indicator
EIA	Electronic Industry Association
EL	Electroluminescent
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMCFA	Electromagnetic Compatibility Frequency Analysis
EME	Earth Mean Equator
EMI	Electromagnetic Interference
EMR	Executive Management Review
EMS	Engineering Master Schedule
EMU	Extravehicular Mobility Unit
EMUDS	Extravehicular Maneuvering Unit Decontamination System
EO	Electro-optic
EOL	End of Life
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPS	Electrical Power System
ERBE	Earth Radiation Budget Experiment
ERRP	Equipment Replacement and Refurbishing Plan
ESR	Engineering Support Request
ESTL	Electronic Systems Test Laboratory
EVA	Extravehicular Activity
F/T	Fault Tolerant
FACC	Ford Aerospace and Communications Corporation
FADS	Functionally Automated Database System

FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FCOS	Flight Computer Operating System
FCR	Flight Control Rooms
FDDI	Fiber Distributed Data Interface
FDF	Flight Dynamics Facility
FDMA	Frequency-Division Multiple Access
FEID	Flight Equipment Interface Device
FETMOS	Floating Gate Election Tunneling Metal Oxide Semiconductor
FF	Free Flier
FFT	Fast Fourier Transform
FIFO	First in First Out
FIPS	Federal Information Processing Standards
fl	foot lambert - Unit of Illumination
FM	Facility Management
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FO	Fiber-Optics
FO/FS/R	Fail-Operational/Fail Safe/Restorable
FOC	Fiber-Optic Cable
FODB	Fiber-Optic Data Bus
FODS	Fiber Optic Demonstration System
FPR	Federal Procurement Regulation
FQR	Formal Qualification Review
FSD	Full-Scale Development
FSE	Flight Support Equipment
FSED	Full Scale Engineering Development
FSIM	Functional Simulator
FSW	Flight Software
FTA	Fault Tree Analysis
FTMP	Fault Tolerant Multi-Processor
FTSC	Fault Tolerant Space Computer
GaAs	Gallium Arsenide
GaAsP	Gallium Arsenic Phosphorus
GaInP	Gallium Indium Phosphorus
GaP	Gallium Phosphorous
GAPP	Geometric Arithmetic Parallel Processor

Gbps	Gigabits Per Second
GBSS	Ground Based Support System
GEO	Geosynchronous Earth Orbit
GEP	Gas Election Phosphor
GFC	Ground Forward Commands
GFE	Government-Furnished Equipment
GFP	Government-Furnished Property
GFY	Government Fiscal Year
GIDEP	Government/Industry Data Exchange Program
GMM	Geometric Math Model
GMS	Geostationary Meteorological Satellite
GMT	Greenwich Mean Time
GMW	Generic Maintenance Work Station
GN&C	Guidance, Navigation, and Control
GPC	General-Purpose Computer
GPP	General-Purpose Processor
GPS	Global Positioning System
GRO	Gamma Ray Observatory
GSC	Ground Service Center
GSE	ground Support Equipment
GSFC	(Robert H.) Goddard Space Flight Center
GTOSS	Generalized Tethered Object System Simulation
H/W	Hardware
HAL	High-Order Algorithmic Language
HDDR	Help Desk Discrepancy Report
HDDR	High Density Digital Recording
HEP	Heterogeneous Element Processor
HFE	Human Factors Engineering
HIPO	Hierarchical Input Process Output
HIRIS	High Resolution Imaging Spectrometer
HM1	Habitation Module One
HM	Habitation Module
HOL	High Order Language
HOS	High Order Systems
HPP	High Performance Processors
HRIS	High Resolution Imaging Spectrometer
I	Interactive

I/F	Interface
I/O	Input/Output
IBM	IBM Corporation
IC	Intercomputer
ICAM	Integrated Computer-Aided Manufacturing
ICB	Internal Contractor Board
ICD	Interface Control Document
ICOT	Institute (for new generation) Computer Technology
ICS	Interpretive Computer Simulation
ID	Interface Diagram
ID	Identification
IDM	Intelligent Database Machine
IDMS	Information and Data Management System
IEEE	Institute of Electrical and Electronic Engineers
IEMU	Integrated Extravehicular Mobility Unit
IF	Intermediate Frequency
IFIPS	International Federation of Industrial Processes Society
ILD	Injector Laser Diode
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
IOC	Initial Operating Capability
IOP	Input/Output Processor
IPCF	Interprocess Communications Facility
IPC	Interprocesses Communication
IPL	Initial Program Load
IPR	Internal Problem Report
IPS	Instrument Pointing System
IR	Infrared
IR&D	Independent Research and Development
IRN	Interface Revision Notices
ISA	Inertial Sensor Assembly
ISA	Instruction Set Architecture
ISDN	Integration Services Digital Network
ISO	International Standards Organization
ITAC-O	Integration Trades and Analysis-Cycle 0
ITT	International Telegraph and Telephone
IV&V	Independent Validation and Verification

IVA	Intravehicular Activity
IWS	Intelligent Work Station
JPL	Jet Propulsion Laboratory
JSC	(Lyndon B.) Johnson Space Center
KAPSE	Kernal APSE
KEE	Knowledge Engineering Environment
KIPS	Knowledge Information Processing System
KOPS	Thousands of Operations Per Second
KSA	Ku-band, Single Access
KSC	(John F.) Kennedy Space Center
Kbps	Kilobits per second
Kipc	Thousand instructions per cycle
LAN	Local-Area Network
LaRC	Langley Research Center
LCC	Life-Cycle Cost
LCD	Liquid Crystal Display
LDEF	Long-Duration Exposure Facility
LDR	Large Deployable Reflector
LED	Light-Emitting Diode
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LIDAR	Laser-Instrument Distance and Range
LIFO	Last In First Out
LIPS	Logical Inferences Per Second
LISP	List Processor
LisP	List Processor
LLC	Logical Link Control
LMI	LISP Machine Inc.
LN_2	Liquid Nitrogen
LNA	Low-noise Amplifier
LOE	Level of Effort
LOE	Low-earth Orbit Environments
LOS	Loss of Signal
LPC	Linear Predictive Coding
LPS	Launch Processing System
LRU	Line-Replaceable unit
LSA	Logistic Support Analysis

LSAR	Logistic Support Analysis Report
LSE	Language Sensity Editors
LSI	Large-scale Integration
LTV	LTV Aerospace and Defense Company, Vought Missiles Advanced Programs Division
LZPF	Level 0 Processing Facility
M	Manual
µP	Microprocessor
MA	Multiple Access
MA	Managing Activity
MAPSE	Minimum APSE
Mbps	Million Bits Per Second
MBPS	Million Bits Per Second
MCAIR	McDonnell Aircraft Company
MCC	Mission Control Center
MCC	Microelectronics and Computer Technology Corp.
MCDS	Management Communications and Data System
MCM	Military Computer Modules
MCNIU	Multi-compatible Network Interface Unit
MDAC-HB	McDonnell Douglas Astronautics Company-Huntington Beach
MDAC-STL	McDonnell Douglas Astronautics Company-St. Louis
MDB	Master Data Base
MDC	McDonnell Douglas Corporation
MDMC	McDonnell Douglas Microelectronics Center
MDRL	McDonnell Douglas Research Laboratory
MFLOP	Million Floating Point Operations
MHz	Million Hertz
MIMO	Multiple-Input Multiple-Output
MIPS	Million (machine) Instructions Per Second
MIT	Massachusetts Institute of Technology
MITT	Ministry of International Trade and Industry
MLA	Multispectral Linear Array
MMI	Man Machine Interface
MMPF	Microgravity and Materials Process Facility
MMS	Module Management System
MMS	Momentum Management System
MMU	Mass Memory Unit

MMU	Manned Maneuvering Unit
MNOS	Metal-Nitride Oxide Semiconductor
MOC	Mission Operations Center
MOI	Moment of Inertia
MOL	Manned Orbiting Laboratory
MOS	Metal Oxide Semiconductor
MPAC	Multipurpose Application Console
MPS	Materials, Processing in Space
MPSR	Multi-purpose Support Rooms
MRMS	Mobile Remote Manipulator System
MRWG	Mission Requirements Working Group
MSFC	(George C.) Marshall Space Flight Center
MSI	Medium-Scale Integration
MSS	Multispectral Scanner
MTA	Man-Tended Approach
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
MTU	Master Timing Unit
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NASPR	NASA Procurement Regulation
NBO	NASA Baseline
NBS	National Bureau of Standards
NCC	Network Control Center
NFSD	NASA FAR Supplement Directive
NGT	NASA Ground Terminals
NHB	NASA Handbook
NISDN	NASA Integrated System Data Network
NIU	Network Interface Unit
NL	National Language
NLPQ	National Language for Queuing Simulation
NMI	NASA Management Instruction
NMOS	N-Channel Metal-Oxide Semiconductor
NMR	N-Modular Redundant
NOS	Network Operating System
NS	Nassi-Schneidermann
NSA	National Security Administration

NSF	National Science Foundation
NSTS	National Space Transportation System
NTDS	Navy Tactical Data System
NTE	Not To Exceed
NTRL	NASA Technology Readiness Level
NTSC	National Television Standards Committee
Nd:YAG	Neodynium Yttrium Aluminum Garnet (laser type)
O&M	Operations and Maintenance
O/B	Onboard
OASCB	Orbiter Avionics Software Control Board
OCN	Operations and Control Network, Operational Control Networks
ODB	Operational Data Base
ODBMS	Onboard Data Base Management System
OEL	Operating Events List
OES	Operating Events Schedule
OID	Operations Instrumentation Data
OLTP	On Line Transaction Processing
OMCC	Operations Management and Control Center
OMV	Orbital Maneuvering Vehicle
ONR	Office of Naval Research
ORU	Orbital Replacement Unit
OS	Operating System
OSE	Orbit Support Equipment
OSI	Open Systems Interconnect
OSM	Orbital Service Module
OSSA	Office of Space Science and Applications
OSTA	Office of Space and Terrestrial Application
OSTDS	Office of Space Tracking and Data Systems
OTV	Orbital Transfer Vehicle
P&SA	Payload and Servicing Accommodations
P/L	Payload
PA	Product Assurance
PAM	Payload Assist Module
PASS	Primary Avionics Shuttle Software
PBX	Private Branch Exchange
PC	Personal Computer
PCA	Physical Configuration Audit

PCA	Program Change Authorization
PCM	Pulse Code Modulation
PCR	Program Change Request
PDP	Plazma Display Panel
PDR	Preliminary Design Review
PDRD	Program Definition and Requirements Document
PDRSS	Payload Deployment and Retrieval System Simulation
PILS	Payload Integration Library System
PIN	Personal Identification Number
PLA	Programmable Logic Array
PLAN	Payload Local Area Network
PLSS	Payload Support Structure
PMAD	Power Management and Distribution
PMC	Permanently Manned Configuration
PN	Pseudonoise
POCC	Payload Operations Control Center
POP	Polar Orbiter Platform
POPCC	Polar Orbit Platform Control Center
POPOCC	POP Operations Control Center
PRISM	Prototype Inference System
PSA	Problem Statement Analyzer
PSA	Preliminary Safety Analysis
PSCN	Program Support Communications Network
PSL	Problem Statement Language
PTR	Problem Trouble Report
QA	Quality Assurance
R	Restricted
R&D	Research and Development
R&QA	Reliability and Quality Assurance
R/M/A	Reliability/Maintainability/Availability
R/T	Real Time
RAD	Unit of Radiation
RAM	Random Access Memory
RAP	Relational Associative Processor
RC	Ring Concentrator
RCA	RCA Corporation
RCS	Reaction Control System

RDB	relational Data Base
RDC	Regional Data Center
REM	Roentgen Equivalent (man)
RF	Radio Frequency
RFC	Regenerative Fuel Cell
RFI	Radio Frequency Interference
RFP	Request for Proposal
RGB	Red-Green-Blue
RID	Review Item Disposition
RID	Revision Item Description
RISC	Reduced Instruction Set Computer
RMS	Remote Manipulator System
RMSE	Root Mean Square Error
RNET	Reconfiguration Network
ROM	Read Only Memory
ROTV	Reuseable Orbit Transfer Vehicle
RPMS	Resource Planning and Management System
RS	Reed-Solomon
RSA	Rivest, Skamir and Adleman (encryption method)
RTX	Real Time Execution
S&E	Sensor and Effector
S/C	Spacecraft
S/W	Software
SA	Single Access
SA	Structured Analysis
SAAX	Science and Technology Mission
SAE	Society of Automotive Engineers
SAIL	Shuttle Avionics Integration Laboratory
SAIS	Science and Applications Information System
SAR	Synthetic Aperture Radar
SAS	Software Approval Sheet
SASE	Specific Application Service Elements
SATS	Station Accommodations Test Set
SBC	Single Board Computer
SC	Simulation Center
SCR	Software Change Request
SCR	Solar Cosmic Ray

SCS	Standard Customer Services
SDC	Systems Development Corporation
SDP	Subsystem Data Processor
SDR	System Design Review
SDTN	Space and Data Tracking Network
SE&I	Systems Engineering and Integration
SEI	Software Engineering Institute
SESAC	Space and Earth Scientific Advisory Committee
SESR	Sustaining Engineering System Improvement Request
SESS	Software Engineering Standard Subcommittee
SEU	Single Event Upset
SFDU	Standard Format Data Unit
SI	International System of Units
SIB	Simulation Interface Buffer
SIFT	Software Implemented Fault Tolerance
SIMP	Single Instruction Multi-Processor
SIRTF	Shuttle Infrared Telescope Facility
SLOC	Source Lines of Code
SMC	Standards Management Committee
SMT	Station Management
SNA	System Network Architecture
SNOS	Silicon Nitride Oxide Semiconductor
SNR	Signal to Noise Ratio
SOA	State Of Art
SOPC	Shuttle Operations and Planning Complex
SOS	Silicon On Saphire
SOW	Statement of Work
SPC	Stored Payload Commands
SPF	Software Production Facility
SPF	Single-Point Failure
SPR	Spacelab Problem Reports
SPR	Software Problem Report
SQA	Software Quality Assurance
SQAM	Software Quality Assessment and Measurement
SQL/DS	SEQUEL Data System
SRA	Support Requirements Analysis
SRAM	Static Random Access Memory

SRB	Software Review Board
SRC	Specimen Research Centrifuge
SREM	Software Requirements Engineering Methodology
SRI	Stanford Research Institute
SRM&QA	Safety, Reliability, Maintainability, and Quality Assurance
SRMS	Shuttle Remote Manipulator System
SRR	System Requirements Review
SS	Space Station
SSA	Structural Systems Analysis
SSA	S-band Single Access
SSCB	Space Station Control Board
SSCC	Station Station Communication Center
SSCR	Support Software Change Request
SSCS	Space Station communication system
SSCTS	Space Station communications and tracking system
SSDMS	Space Station data management system
SSDR	Support Software Discrepancy Report
SSDS	Space Station data system
SSE	Software Support Environment
SSEF	Software Support Environment Facility
SSIS	Space Station Information System
SSME	Space Shuttle Main Engine
SSO	Source Selection Official
SSOCC	Space Station Operations Control System
SSOCC	Space Station Operations Control Center
SSOL	Space Station Operation Language
SSON	Spacelab Software Operational Notes
SSOS	Space Station Operating System
SSP	Space Station Program
SSPE	Space Station Program Element
SSPO	Space Station Program Office
SSSC	Space Station Standard Computer
SSST	Space Station System Trainer
STAR	Self Test and Recovery (repair)
STARS	Software Technology for Adaptable and Reliable Software
STDN	Standard Number
STI	Standard Technical Institute

STO	Solar Terrestrial Observatory
STS	Space Transportation System
SUSS	Shuttle Upper Stage Systems
SYSREM	System Requirements Engineering Methodology
Si	Silicon
SubACS	Submarine Advanced Combat System
TAI	International Atomic Time
TBD	To Be Determined
TBU	Telemetry Buffer Unit
TC	Telecommand
TCP	Transmissions Control Protocols
TCS	Thermal Control System
TDASS	Tracking and Data Acquisition Satellite System
TDM	Technology Development Mission
TDMA	Time-Division Multiple Access
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TFEL	Thin Film Electrolumenescent
THURIS	The Human Role in Space (study)
TI	Texas Instruments
TM	Technical Manual
TM	Thematic Mapper
TMDE	Test, Measurement, and Diagnostic Equipment
TMIS	Technical and Management Information System
TMP	Triple Multi-Processor
TMR	Triple Modular Redundancy
TMS	Thermal Management System
TPWG	Test Planning Working Group
TR	Technical Requirement
TRAC	Texas Reconfigurable Array Computer
TRIC	Transition Radiation and Ionization Calorimeter
TSC	Trade Study Control
TSIP	Technical Study Implementation Plan
TSP	Twisted Shielded Pair
TSS	Tethered Satellite System
TT&C	Telemetry, Tracking, and Communications
TTC	Telemetry Traffic Control

TTR	Timed Token Ring
TWT	Traveling-Wave Tube
U	Non-restrictive
UCC	Uniform Commercial Code
UDRE	User Design Review and Exercise
UIL	User Interface Language
UON	Unique Object Names
UPS	Uninterrupted Power Source
URN	Unique Record Name
UTBUN	Unique Telemetry Buffer Unit Name
UTC	Universal Coordinated Time
V&V	Validation and Verification
VAFB	Vandenberg Air Force Base
VAX	Virtual Address Exchange
VHSIC	Very High-Speed Integrated Circuit
VLSI	Very Large-Scale Integration
VLSIC	Very Large-Scale Integrated Circuit
VV&T	Validation, Verification and Testing
WAN	Wide Area Network
WBS	Work Breakdown Structure
WBSP	Wideband Signal Processor
WDM	Wavelength Division Multiplexing
WP	Work Package
WRO	Work Release Order
WS	Workstation
WSGT	White Sands Ground Terminal
WTR	Western Test Range
XDFS	XEROX Distributed File System
YAPS	Yet Another Production System
ZOE	Zone Of Exclusion
ZONC	Zone Of Non-Contact
ZnS	Zinc Sulfide

TASK 3 – TRADE STUDIES

INTRODUCTION

The primary objective of Task 3 is to provide additional analysis and insight necessary to support key design/programmatic decision for options quantification and selection for system definition. This includes: (1) the identification of key trade study topics, (2) the definition of a trade study procedure for each topic (issues to be resolved, key inputs, criteria/weighting, methodology), (3) conduct tradeoff and sensitivity analysis, and (4) the review/verification of results within the context of evolving system design and definition.

Trade studies represent a systematic mechanism for deriving preferred alternatives within a specific domain of interest. These domains of interest (trade study topic) may be quite global in nature (i.e., standardization) and cut across many technology/design boundaries or highly localized to focus on a specific design problem. Such considerations must be organized into a logical and structured framework to facilitate trade study scheduling, integration (both with other trade studies and with system design needs), and validation. This framework is the systematic design approach shown in Figure 1 where trade studies are directly supportive of architectural needs both in scope and level of design detail. Trade studies provide the insight within specific domains of interest to support the stepwise refinement of design detail. This approach promotes interaction between successive design steps and provides enhanced visibility/traceability for key decisions.

Trade study topics are actually "domains of interest" that include a number of interrelated issues that cannot be easily "decoupled" or form a logical technology related subset. These topics may include one or more "tradeoffs" that attempt to resolve the key issues identified. The primary source of trade data was developed under Task 2 (options development). This required an integrated Task 2/3 approach to insure that all trade study objectives were achieved.

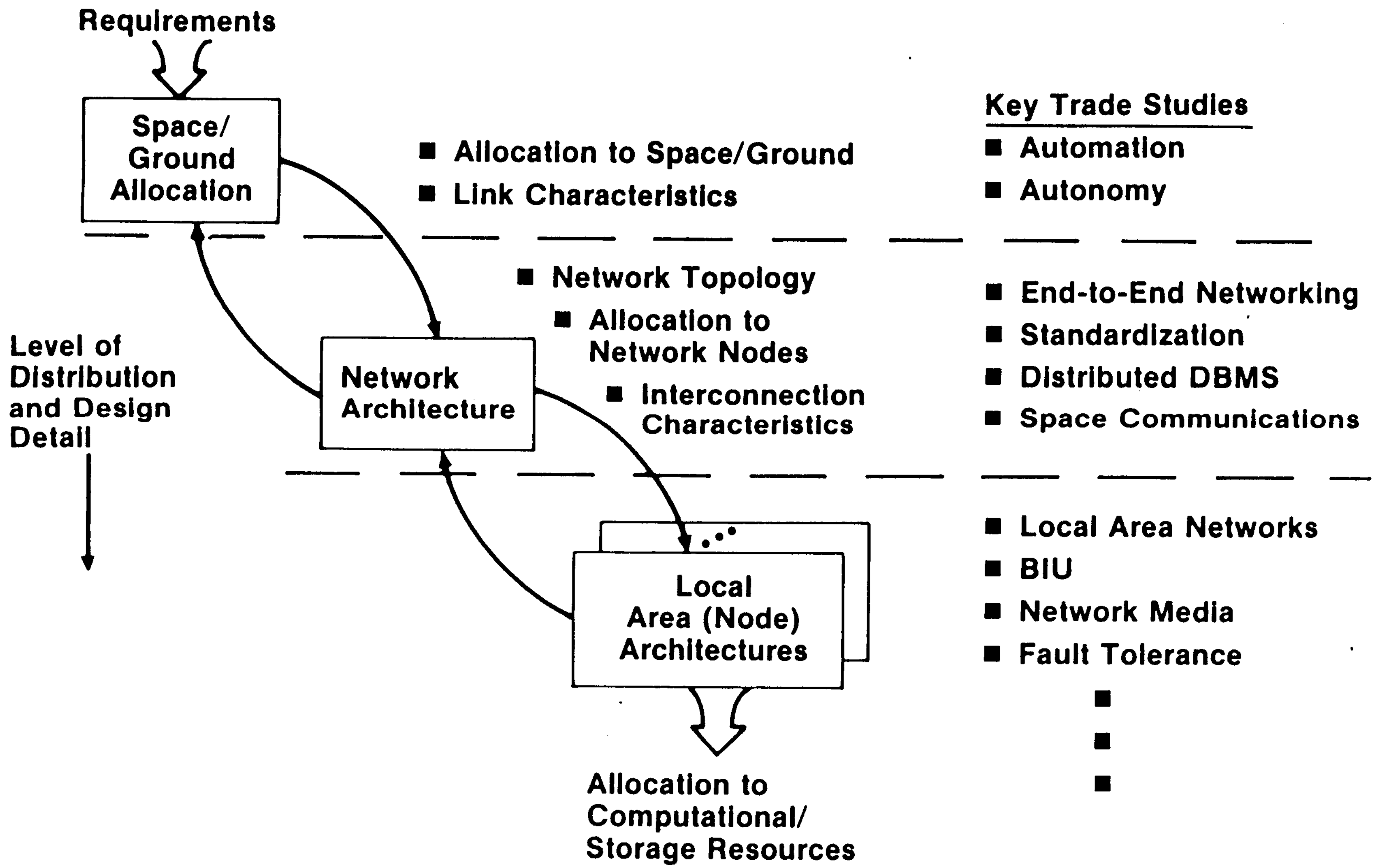


Figure 1. Relationship Between Trade Studies and System Design

In general, trade studies have many aspects that are quite unique to the specific topic. These unique aspects are dictated by design/programmatic needs as well as the nature of the issues to be addressed. However, these needs are addressed within the framework of a systematic trade study methodology. This includes the following fundamental concepts.

1. The establishment of a set of generic trade criteria as guidelines to be applied to all trade study areas (see Table 1). Trade study unique criteria will be developed within the context of each area and will include all relevent Task 1 requirements.

2. The development of trade study definition reports (work packages) that can be reviewed prior to conduct of the study.

3. Adherence to sound system engineering practices that includes traceability to requirements and sensitivity analysis.

4. Extensive peer group review.

TASK APPROACH

This section will describe the steps that define the task methodology and approach. The key steps include:

1. Identify/Prioritize Trade Study Topics
2. Develop Individual Trade Study Definition Workpackages
3. Definition Workpackage Review
4. Conduct Trade Study
5. Trade Study Documentation
6. Review and Validation

A list of trade study topics was developed early in the program based on emerging design/programmatic drivers that were identified during requirements definition (Task 1) efforts. The topics were organized to accommodate a

Table 1. Trade Study Criteria

System generic

- Cost
  - Development (nonrecurring)
  - Unit (recurring)
  - Life cycle (training, maintenance, operation)
- Risk
  - Development (technology readiness)
  - Production (producibility, cost/schedule)
- Performance (specific parameters are trade-study unique)
- Standardization/commonality
  - Availability of supported standards
  - Degree of commonality potential
- Growth/technology insertion potential

Onboard hardware generic

- Physical characteristics (volume, weight, power, thermal)
- Environment characteristics (radiation tolerance, etc.)
- Reliability/availability/maintainability

Unique criteria for individual trades

logical mapping of option categories into trade study areas. As system definition (Task 4) activities progressed, this mapping, the list of trade study topics and the associated prioritization of topics were refined to reflect evolving architectural needs. Table 2 identifies the current list of active trade study topics in priority order. Note that the priority ordering does not necessarily reflect criticality but rather the sequence and interaction required to support the system definition process. Many of these topics have a one-to-one correspondence with Task 2 option categories and the corresponding options information base provides the primary source of inputs. Other topics represent a mapping of several option categories, some of which are required for other trade studies or key design/programmatic decisions.

Once a prioritized trade study was initiated, a formal problem definition was developed and documented in the form of a workpackage. These definition workpackages were subjected to Team and NASA review as a mechanism for focusing trade study activities. This definition workpackage includes the following items:

1. Reason for Trade Study. Purpose and objectives of the trade study with supporting rationale.

2. Background. Supporting descriptive data that establishes context for the study. Includes references to key driving requirements that will influence the study.

3. Issues. This section identifies major issues that the trade study will address and attempt to resolve.

4. Applicable Options. Identification of option categories that will be a primary source of input parameters for this study.

5. Trade Study Criteria. Identifies all generic and study-unique trade criteria that will be considered in the tradeoff analysis. Criteria will include all relevent requirements developed by Task 1. Weighting of criteria will be addressed during the trade study.

Table 2
TRADE STUDY STATUS

TRADE STUDIES	DEFINITION INITIATED	DEFINITION COMPLETE	GSFC Review TRADE ANALYSIS INITIATED	PRELIMINARY PRESENTATION	NASA Review PRELIMINARY DOCUMENTATION
SPACE AUTONOMY	X		X	11/84	5/85
FUNCTION AUTOMATION	X		X	11/84	5/85 (1)
SOFTWARE TRANSPORTABILITY	X	8/85	X		8/85
SYSTEM NETWORK TECHNOLOGY	X	12/84	X	2/85	5/85
COMMUNICATIONS STANDARDIZATION	X	12/84	X	2/85	5/85
ONBOARD LOCAL AREA NETWORKING	X	11/84	X	2/85	5/85
BIU/TRANSMISSION MEDIA	X	11/84	X	2/85	(3)
DISTRIBUTED OPERATING SYSTEM	X	3/85	X		5/85 (4)
SOFTWARE DEVELOPMENT	X	3/85	X		5/85
FAULT-TOLERANT COMPUTING	X	3/85	X		5/85
SPACE QUAL. COMPUTERS	X	3/85	X		5/85
DISTR. DATA BASE MANAGEMENT	X	3/85	X		5/85
SYSTEM INT., TEST., & VERIF.	X	3/85	X		8/85
CREW WORKSTATIONS	X	11/84	X		5/85
LANGUAGES - HIGHER ORDER & TEST	X				5/85
MASS STORAGE	X	3/85	X		5/85
SPACE COMMUNICATIONS	X	3/85	X		8/85
COMMAND AND RESOURCE MANAGEMENT	X	5/85	X		5/85 (5)

(1) Combined with Space Autonomy - New Title: Space Autonomy and Function Automation
(3) Incorporated into Onboard LAN Study
(4) Two Studies: Software Configuration Management and Software Development Environment Facility
(5) New Study performed because of importance to System Definition

6. Methodology and Approach. General description of procedure and any special tools or techniques employed.

Once a trade study workpackage had been reviewed and approved, the actual conduct of the tradeoff analysis/evaluation was initiated. Trade study procedures were generally tailored to specific topics, however, systemmatic engineering processes were applied as appropriate. This includes a sensitivity analysis to determine the factors that contribute most to the relative ranking of top alternatives. Sensitivity analyses provide added insight in assessing the study results to determine design and programmatic driving factors. They are also used to identify technology items that could have significant payoff (performance or cost) but are currently perceived to have unacceptable elements of risk. These technology items may be candidates for advanced technology development and demonstration. Once preliminary study results are available, a trade study report is developed to provide preliminary documentation from Team/NASA review and validation.

SUMMARY

The preliminary Task 3 (Trade Studies) documentation included in this report has been organized into separate trade study reports and packaged as two volumes. Only those trade studies that directly influence major SSDS system design decisions are included in this report. These are identified in Table 2.

Table 3 shows a summary of the Sections of this report and the respective Trade Studies for each section. It also shows which sections are contained in the respective volumes.

Table 3

	SECTION	TRADE STUDY
VOLUME I	I.	SPACE AUTONOMY AND FUNCTION AUTOMATION
	II.	SOFTWARE TRANSPORTABILITY
	III.	SYSTEM NETWORK TOPOLOGY
	IV.	COMMUNICATIONS STANDARDIZATION
	V.	ONBOARD LOCAL AREA NETWORKING
	VI.	DISTRIBUTED OPERATING SYSTEM
	VII.	SOFTWARE CONFIGURATION MANAGEMENT
	VIII.	SOFTWARE DEVELOPMENT ENVIRONMENT FACILITY
VOLUME II	IX.	SOFTWARE DEVELOPMENT TEST & INTEGRATION CAPABILITY
	X.	FAULT TOLERANT COMPUTING
	XI.	SPACE QUALIFIED COMPUTERS
	XII.	DISTRIBUTED DATA BASE MANAGEMENT SYSTEM
	XIII.	SYSTEM INTEGRATION TEST AND VERIFICATION
	XIV.	CREW WORKSTATION
	XV.	MASS STORAGE
	XVI.	COMMAND AND RESOURCE MANAGEMENT
	XVII.	SPACE COMMUNICATIONS

I. SPACE AUTONOMY AND FUNCTION AUTOMATION

SPACE AUTONOMY AND FUNCTION AUTOMATION TRADE STUDY

1.0 INTRODUCTION

a. Trade Study Objective. This trade study is performed to identify and develop design requirements (characteristics that reflect level of automation) for each SSDS function and to allocate the SSDS function in total or in some distributed fashion, to space or ground, for both IOC (Initial operational Capability) and evolutionary growth of the Space Station program.

b. Definitions Related to Autonomy/Automation. To facilitate technical discussions on the trade study, a set of definitions of terminologies related to automation and autonomy are abstracted from various NASA and other documents as follows:

Autonomy: The ability to function as an independent unit or element, over an extended period of time, performing a variety of actions necessary to achieve pre-designated objectives, while responding to stimuli produced by integrally-contained sensors.

Automation: The ability to carry out a pre-designated function or series of actions, after being initiated by an external stimulus, without the necessity of further human intervention.

Telepresence: The ability to transfer a human's sensory perceptions (e.g., visual, tactile, etc.) to a remote site.

Teleoperation: Remote manipulation in which humans are responsible for generating control signals.

Robot: A generic term, connotating many of the following ideas: A mechanism capable of manipulation of objects and/or movement having enough internal control, sensing, and computer analysis so as to carry out a more or less sophisticated task. The term usually connotes a certain degree of autonomy, and an ability to react appropriately to changing conditions in its environment.

Robotics: The technology by which machines perform all aspects of an action, including sensing, analysis, planning, direction/control, and effecting/manipulation, with human supervision.

Space Autonomy: The independence of the onboard subsystems from direct, real-time control by the ground (crew or machines) for a specified period of time.

Artificial Intelligence: A discipline which attempts to simulate or duplicate the efficient problem - solving capabilities of humans.

Expert System: A knowledge-based system which stores, processes, and utilizes a large data base of information concerning a specific area of knowledge to solve problems pertaining to that area. Expert systems are not self-adaptive but do provide the ability to generate new concepts and relationship about knowledge already in the data base.

1.1 BACKGROUND

a. Advanced Technology Advisory Committee Study. The Advanced Technology Advisory Committee (ATAC) has provided recommendations on automation and robotics options for use by contractors in their Phase B Space Station definitions and preliminary designs [1]. The ATAC final report published in April 1985, among other things, will assess the impact of the various automation concepts for use in Space Station. The assessment study performed by Stanford Research, Inc. (SRI) International, determines the automation levels which would be technically feasible about 10 years after the Initial Operational Capability (IOC) has been established. The ATAC studies not only identify the feasible automation levels but also design features which are required by IOC to enable the integration of enhanced automation capabilities for future hardware/software upgrades, both onboard and ground. These reports are currently being assessed for impact on SSDS System definition.

b. <u>Benefits of Automation and Autonomy.</u> Task 1 developed a function list and the corresponding functional performance requirements for SSDS functions. Each of these functions will be allocated to onboard and/or ground. It is likely that all or nearly all of the allocated functions are automated more or less for software implementation. The advantages of SSDS function automation can be summarized as follows:

(1) Lower life Cycle Cost

- o Functional operations are performed by Data Processing (DP) hardware/software instead of man.
- o Autonomy minimizes (or eliminates) dependence on communication links.

(2) Increase Productivity

- o Minimize chances for human error
- o Free crew from monotonous, boring, repetitious activities
- o Optimize crew/operator resources in core or payload
- o Improve system performance

(3) Time Responsivity

- o Meet time critical requirements
- o Improve response times

(4) Safety

- o Minimize hazardous (human) operations

c. <u>Methods of Achieving Automation/Autonomy.</u> Automation is the keynote of this study. Automation techniques, which can be applied to achieve autonomy, include artificial intelligence (AI), teleoperation, telepresence and robotics as defined above. In addition, there are widely applied conventional (or often referred to as algorithmic) automation approaches. By definition, a conventional approach is an automation technique whereby a machine is programmed to respond to a predefined set of conditions with a predefined set of actions. The actions, which may be conditional, can be accomplished by use of such programming language as "IF-THEN-ELSE" statements. Responses, however, are governed completely by the designer's ability to anticipate the situations which the machine will encounter. Therefore, conventional (or algorithmic) automation works best for well defined situations. Artificial intelligence is known as a branch of computer science dedicated to the design and implementation of computer programs that make human-like decisions, and can be adaptive and more proficient at making decisions. AI systems, such as expert systems, interact with their operators in a "natural" way which mimics intelligent behavior.

A closely related trade study on AI Automation will determine the applicability of the advanced AI automation techniques to SSDS functions for IOC and evolutionary growth of the Space Station program.

1.2 ISSUES

a. Cost. Figure 1 shows a copy of NASA's Program Planning Guidelines that indicate a "cost" constraint to achieve an "opportunity autonomous" Space Station. The issue here is to determine the degree of autonomy consistent with the cost constraint. For instance, the CDG's (Concept Development Group) output report, that specified an autonomy requirement for the total ground crew to eventually consist of one person on a Monday through Friday, eight hour per day schedule, clearly satisfied NASA's autonomy goal. However, the cost to achieve this degree of autonomy at a given onboard productivity level was not addressed.

It is commonly agreed that high cost is expected for automation/autonomy software development. Therefore, the allocation of the SSDS functions to onboard and the decision on the degree of function automation for an operationally autonomous Space Station have to be made consistent with the cost constraint.

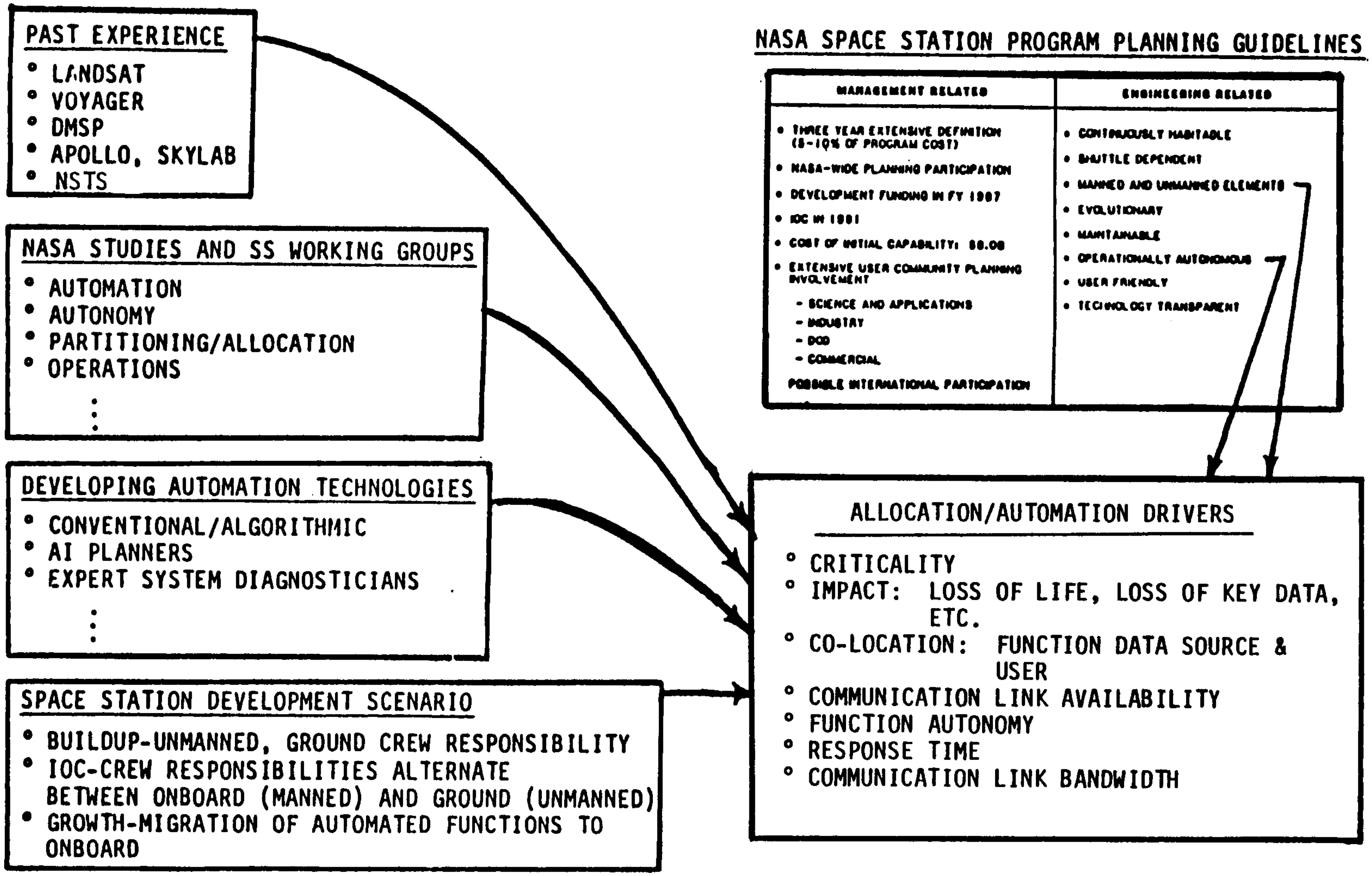


Figure 1. Key Drivers Affecting Allocation/Automation of SSDS Function to Onboard/Ground.

b. Automation Technology Maturity. – As discussed previously, conventional approaches for function automation are well understood and have been widely utilized in many systems. Artificial Intelligence and robotics techniques show potential for space autonomy applications but are not yet mature. A few schedulers have already been developed in the aerospace sector by using expert system approaches and several others are currently under development. It should be noted that, in general, these expert system schedulers are not necessarily reconfigurable to a new application, such as those required for the SSDS. Expert systems are the current state-of-art in AI technology and are in use in many applications. They are not, however, an off-the-shelf item. The availability of tools and methodology to build expert systems tailored to the Space Station applications can be expected for the IOC.

c. Provisions for Growth Past IOC This trade study, will consider not only the SSDS function allocation/ automation for IOC; but also for a) adding/expanding functions as required, b) migrating functions from ground to onboard, and c) increasing the degree of automation past IOC to the year 2000. To meet the study purpose, two cases have been developed as shown in the matrix output provided in section 3.0. The first case is to allow an automated payload/core system in space, if the payload/core commands/data are originated in flight. The second is that to migrate the diagnostics support SSDS function to onboard for growth.

For growth past IOC, preliminary results show great potential for expert systems. As the technology matures, expert system(s) can be used for developing short-term schedules. They can also be used for core or customer systems status monitoring, and for OTV/OMV checkout and diagnostics. A robot may be used in space replacing or supplementing an EVA astronaut to perform many tasks, offering improved safety, productivity, and performance capability.

A separate trade study on AI Automation will discuss in detail the applications of advanced automation techniques, such as robotics and expert systems, to the SSDS functions for IOC and growth of the Space Station Programs.

d. Dependence on Communication Link The space-to-ground communication link is a finite bandwidth resource that must be shared by many users. The demands of the Space Station Program on this link will be very high just to transport primary mission data. The link is also subject to outages because of the zone-of-exclusion and due to system failures. Therefore, minimizing dependence on this link is an important potential benefit of space autonomy.

1.3 TRADE STUDY CRITERIA

1.3.1 Generic. These criteria are generic and are applied to all SSDS trade studies.

a. Life Cycle Cost
- o Development and Maintenance cost of hardware and software.

b. Risk
- o Technical
- o Schedule

c. Safety
- o Crew safety
- o System failure

d. Reliability and Availability
- o Hardware
- o Software

e. Growth
- o Technology insertion
- o Design extendability

1.3.2 Trade Study Unique

As shown in Figure 1, there are seven key drivers used as the trade unique criteria for SSDS function allocation/automation. They are criticality, impact, co-location, communication link availability, function autonomy, response time, and communication link bandwidth. The way they are used for allocating the SSDS functions and assessing degree of automation for function automation will be discussed in Section 2.0. This section provides their definitions as follows.

a. Criticality. It is defined as a single character code with a fixed number to indicate the necessary recovery time for failures involving SSDS:

Numerical Code	Descripion
1	No interruption allowed, redundant
2	Recover within 10 seconds, hot backup
3	Recover within 10 minutes, cold backup
4	Recover within 24 hours, simple repair, LRU (Line Replaceable Unit) available
5	Recover within 21 days, safe haven used until recovered
6	Recover within 90 days, next logistics supply cycle
7	No limit on recovery

It should be noted that the smaller is the numerical value of the indicator, the more critical (shorter) is the time required for recovery when SSDS failures occur.

b. Impact. It is defined with a fixed number to indicate consequences of failures of the SSDS as follows:

Numerical Code	Description
1	Loss of life
2	Hazard, damage to Space Station
3	Damage to Space Station or mission equipment
4	Mission aborted, loss of key data, or economic penalty
5	Crew or operator inconvenience
6	No substantial impact

It should be noted that the smaller the number, the more severe the consequences of the SSDS failures.

c. Physical Co-location of Function Data Source and Function User (crew/customer). This criterion is set for implementing software function in space or on ground where input data is generated.

d. Space/Ground Communication Link Availability. In checking the availability of the telemetry/telecommand transmission link, the link related components, such as blind spot in TDRSS (tracking and data relay satellite system) coverage, link MTBF (mean time between failure) and link MTTR (mean time to recovery), should be considered for allocating SSDS functions to onboard/ground.

e. Function Autonomy. The SSDS functions with significant inter-function input/output rates should be grouped and allocated as a group for function automation.

f. Response Time. It relates to data transmission delay due to space/terrestrial communication links (i.e., the roundtrip TDRSS/DOMSAT delay approximately 2 seconds.

g. Space/Ground Communication Link Bandwidth. During SSDS function allocation, considerations should be given to the finite bandwidth of the communication link allocated to the Space Station.

1.4 Applicable Options. The following options have been defined in detail and are documented in the options development report (Task 2). They are applicable to this trade study.

2.2.2 Autonomy/Automation

2.2.2.2 Function Automation Options

2.2.2.3 Space Station Autonomy (Ground/Space)

a. Options for Autonomy Options for autonomy, in general, can be categorized into three types, viz., space autonomy, ground implementation, and space/ground shared implementation. As defined by NASA, space autonomy means that the onboard subsystems are independent from direct and real-time control by the ground (crew or machine) for a specific period of time. That implies an onboard capability to perform essential subsystem functions, many of which have traditionally been done on the ground. To do these (subsystem) functions onboard with few or no people requires a high degree of automation. This degree of space autonomy depends on what level of automation onboard is achievable and affordable, as it will be discussed in the next section.

b. Options for Automation - Degree of Automation As an SSDS function is allocated to onboard or ground based on the trade unique criteria given above, a decision has to be made on whether the allocated function is to be automated; if so, to what degree will it be automated? A resolution to this question, in general, is that for any onboard-allocated function crew and SSDS resources are required. The degree of automation is an expression of the mix of crew and SSDS resources. The concept of the degree of function automation is delineated as shown in Figure 2. The horizontal line on the figure can be interpreted as a scale for measuring the degree of automation relative to the required amounts of crew and SSDS resources. The left-most point, L, on the scale represents the labor intensive extreme (i.e., the maximal crew resource) while the right-most point, R, represents the automated extreme where no crew resource is required. The portion of the scale between

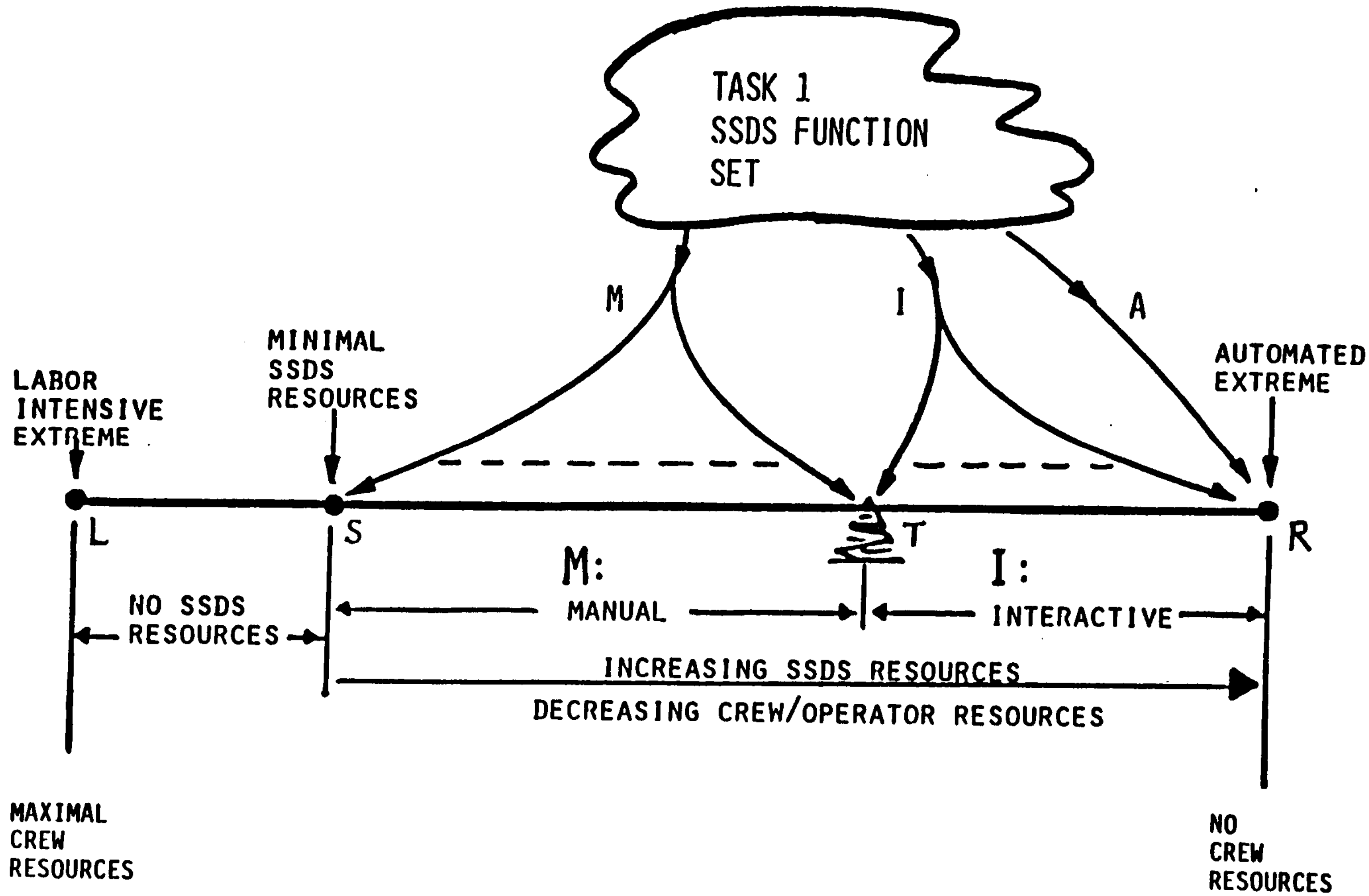


Figure 2. Degree of SSDS Function Automation

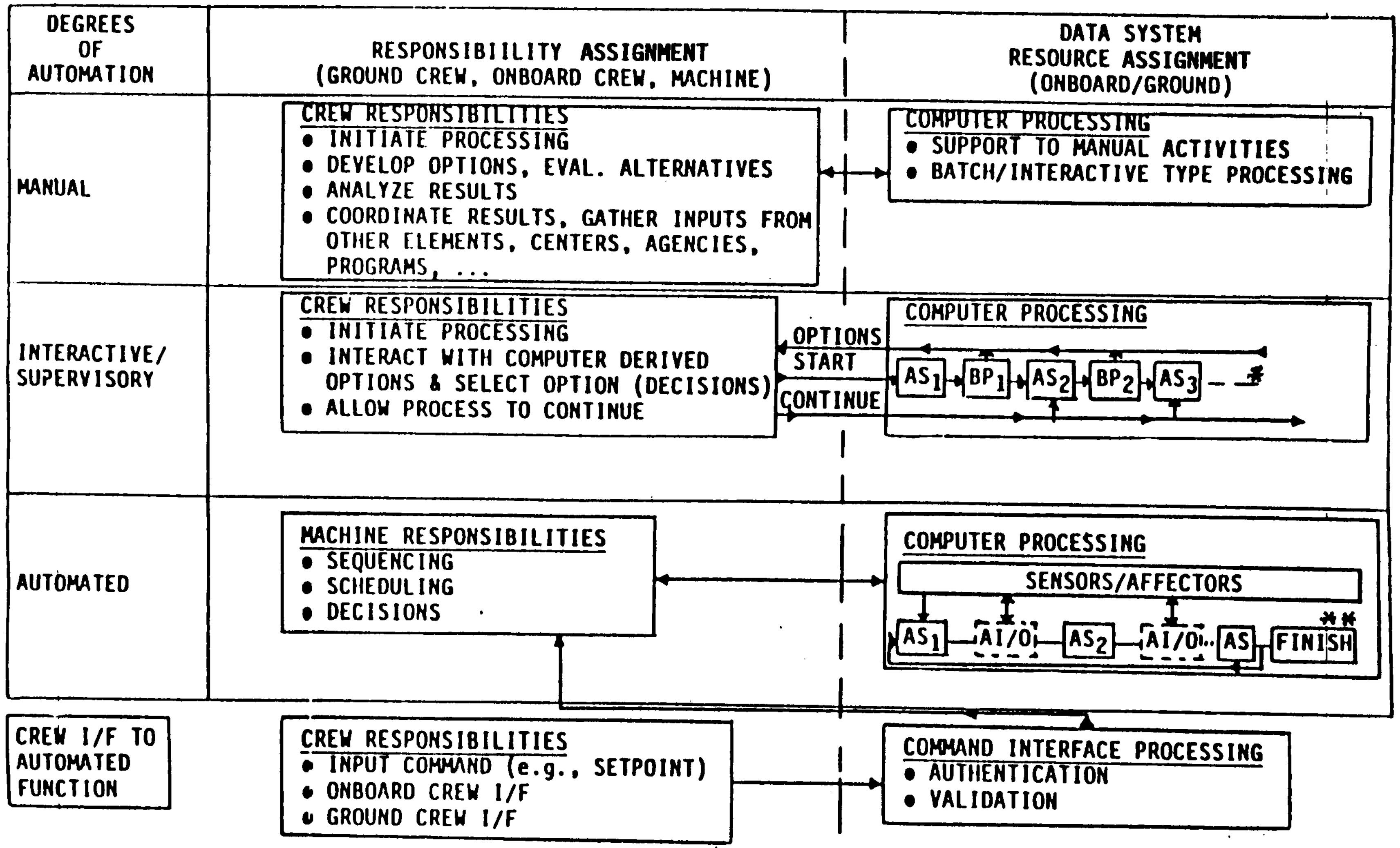
points, S and R, is partitioned into two regions for mapping all the allocated SSDS functions, by three curved lines. They are manual, interactive, and automated lines as shown in Figure 2, and abbreviated as M, I, and A, respectively, to represent the degree of automation for an allocated SSDS function.

The region between points L and S is for any function that requires no SSDS resource. The region between S and T represents the M degree of automation for which an allocated function requires minimal SSDS resource at point S, and requires increasing SSDS resources (with a corresponding decrease in crew/operator activities) proceeding towards point T. The phenomena applies similarly to an allocated function at an I automation level in the interactive automation region between T and R. The automated region at point R, as described above for an allocated function designed at an A automation level represents the automated extreme with maximum SSDS hardware and software requirements for functional implementation.

c. <u>Function Automation and Responsibility/DP Resource Assignment</u> As noted, the SSDS must provide data processing (DP) resources, both hardware and software, for implementing the functions allocated to the SSDS. The type and extent of the DP resources provided for function implementation depends on the designated level and type of automation. Figure 3 depicts the overall relationship between responsibilty assignment (onboard/grond crew, machine) and data system resource assignments (onboard/ground) for the different degrees of function automation.

2.0 METHODOLOGY

Figure 4 depicts the systematic procedures set up by this trade study for producing the matrix output as shown in Section 3.0. The key elements of this procedure are described below.



* AS - Automated Segment
BP - Break Point

** AI/O - Automatic Input/Output

Figure 3. FUNCTION AUTOMATION VS ASSIGNMENT OF SSDS RESOURCES

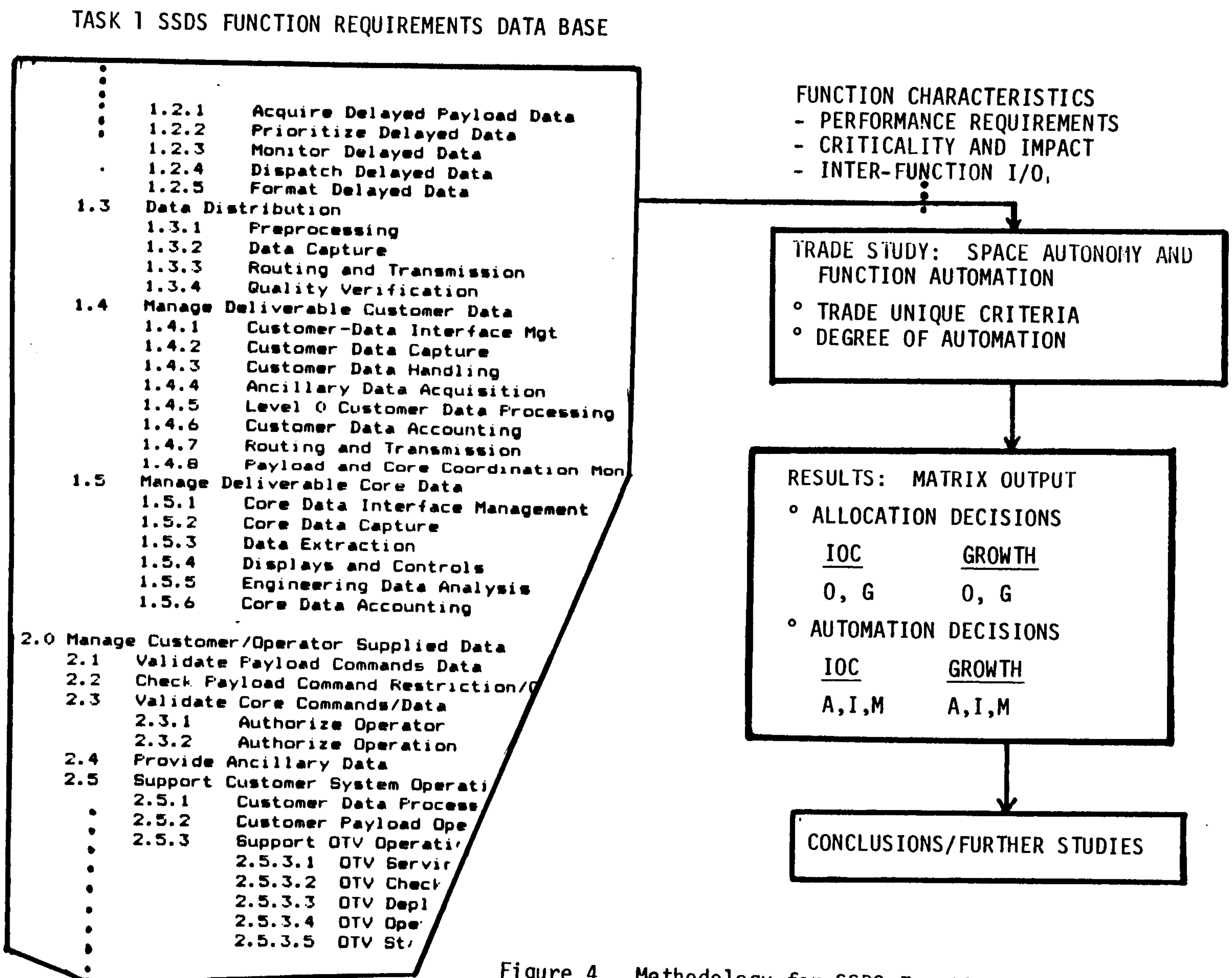


Figure 4. Methodology for SSDS Function Allocation/Automation

a. SSDS Function List Task 1 has defined the functions and the functional performance requirements for the SSDS. The SSDS functional requirements are organized into a hierarchical set of seven top-level functions as follows.

1.0 Manage Customer/Operator Delivered Data
2.0 Manage Customer/Operator Supplied Data
3.0 Schedule and Execute Operations
4.0 Operate Core Systems
5.0 Manage SSDS Facilities
6.0 Develop, Simulate, Integrate, and Train
7.0 Support Space Station Program

The organization of functions is carried from the top-level down to the third and fourth levels to form a complete SSDS function list consistent with the SSDS data flows. This complete 4-level SSDS function list will be used to develop the function allocation/automation matrix as shown in Figure 4 in section 3.0.

b. SSDS Function Requirements Data Base Task 1 has developed the function requirements data base [2]. Included in the requirements data base for each function on the function list are those functional characteristics and performance requirements, such as criticality for recovery time, impact, response time, automation level, allocation location, input/output functional interface, and total data bits in terms of time interval and data rate. These information data parameters are abstracted and evaluated to formulate the matrix output, as described in the following sections.

c. Interface of Trade Unique Criteria and Requirements Data Base As delineated in Figure 4, the matrix output consists of three major portions: the SSDS function list, the assessment of allocation criteria for each function and the resulting decisions for allocation (onboard vs ground) and degree of automation, as illustrated in Figure 5. Taking SSDS function 1.1.1, "Acquire Real-Time Data" as an example the following will illustrate how to interpret time entries under the seven "Allocation Criteria" columns that were derived from the SSDS Function Requirements Data Base: (the seven trade study unique criteria were defined in section 1.3.2).

C1 – Criticality is "2" (recover within 10 seconds)

C2 – Impact is "5" (crew/operator inconvenience)

C3 – Co-location is marked with "Y" (where Y is used as a check mark)

This co-location information is obtained from a program "sort" (through the function requirements data base), that shows all the functions of 1.1.1, 1.1.2, ——, 1.1.5 under function 1.1.

C4 – Communication Link Availability is marked with "Y".

This information is obtained by observing the following:

- o A program "sort" (an input/output function interface).
- o Function 1.1.1 is output to Function 1.3.2, Data Capture.
- o Function 1.1.1 is allocated to onboard whereas Function 1.3.2 is allocated on the ground.

As a result, the communication link availability is required for functional interface (for data transmission from space to ground) between these functions, one onboard and one on ground.

(5) Function Autonomy is marked with "Y"

(significant interaction with other SSDS functions)

(6) Response Time is marked with "Y"

(Data base shows a response time of 2000 Ms)

(7) Communication Link Bandwidth is marked with "Y"

(data base shows data rate is 1330 K bits/second at a one-second time interval)

3.0 RESULTS

Figure 5, SSDS Function Allocation/Automation Criteria and Decisions, is the final product of this trade study. It contains the preliminary decisions for function allocation to onboard and/or ground, and for the degree of function automation for each SSDS function. It also includes the assessment of criteria extracted from the requirements data base used to derive these decisions.

The column headings, abbreviations, and markings on Figure 5 under allocation criteria and decisions related to each SSDS function, are defined below:

- o The C1, C2, ..., C7 used on the figure are defined below and correspond to the criteria described in section 1.3.2.

  C1: Criticality
  C2: Impact
  C3: Physical co-location between function data source and function user
  C4: Space/ground communication link availability
  C5: Function autonomy
  C6: Response Time
  C7: Space/ground communication bandwidth

- o The numerical code 1, 2, 3, ..., under C1 and C2 represents the level of significance (ranking) of the allocated function as defined in section 1.3.2.

- o The check mark "Y" under the other five trade unique criteria identifies the correlation between the allocated function and the associated criterion.

- O and G under "Decisions Allocation":
  - O: Onboard
  - G: Ground

- A, I, and M under "Decisions Automation":
  - A: Automated (can be any automation technique)
  - I: Interactive
  - M: Manual

  In case of multiple levels of automation assigned to an allocated function, such as "A,I", or "A,I,M," it implies that the allocated function (e.g., subfunctions under 5.1.2, Flight Resource Management, which is relatively large in terms of functional characteristics and performance requirements), is usually implemented with part of the function at Manual level, part of it at interactive level, and part of it at automated level.

- Any markings, such as 1, 2, ..., Y, O, G, A, I, and M assigned only to a higher level function imply that same markings are assigned to all subfunctions under it (without repetition).

4.0 CONCLUSIONS AND REMAINING ISSUES

The trade study has developed an output matrix as shown in Figure 5. This product, however may be subject to updates under the following foreseeable situations.

a. ATAC Final Report The final report of the Advanced Technology Advisory Committee (ATAC) was not available at the time of completion of this trade study. The ATAC report includes recommendations for automation related to the SSDS and could significantly influence the final results of this trade study. Those reports are under evaluation.

b. Task 1 SSDS Function List and Requirements Data Base The SSDS function list provides the basic framework for the allocation/automation matrix output. The allocation of each function to onboard or ground and the assessment of degree of automation to each allocated function are determined by the function characteristics and its performance requirements. Therefore, when SSDS function definition changes, function additions and/or function deletions occur, the SSDS function list and the Requirements Data Base will change. Consequently, the decisions on function allocation/automation will be affected accordingly, and the output matrix will be automatically updated.

c. Specific Automation Technique for Future Assessment. As noted, when an allocated function in the output matrix is assessed with an "A" for function automation, it implies that the function is at the automated extreme, by using any automation techniques. If later trade studies show that expert system (included in AI automation) are cost effective for such functions, then the automation assignment "A" will be changed to an "E" to reflect this recommendation.

5.0 REFERENCES

[1] Summary on the NASA's Advanced Technology Advisory Committee Study, by J. J. Zapalac, as appendix to Options "White Paper" on Autonomy/Automation, Appendix D in SSDS Progress Report for the Month of December 1984.

[2] SSDS Function Requirements Data Base, Appendix A-9 to Task 1 - Function Requirements Definition, DR-5, SSDS Analysis/Architecture Study, MDC H1343, May 1, 1985.

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SSDS FUNCTION LIST	ALLOCATION CRITERIA							DECISIONS			
								ALLOCATION		AUTOMATION	
	C1	C2	C3	C4	C5	C6	C7	IOC	GROWTH	IOC	GROWTH
1.0 Manage Customer/Operator Delivered Data											
1.1 Manage Real Time Data Return	2	5	Y		Y	Y		0	0	A	A
1.1.1 Acquire Realtime Data											
1.1.2 Prioritize Realtime Data				Y			Y				
1.1.3 Monitor Realtime Data											
1.1.4 Dispatch Realtime Data				Y			Y				
1.1.5 Format Realtime Data											
1.2 Manage Delayable Data Return	2	5	Y		Y			0	0	A	A
1.2.1 Acquire Delayed Payload Data											
1.2.2 Prioritize Delayed Data											
1.2.3 Monitor Delayed Data											
1.2.4 Dispatch Delayed Data				Y			Y				
1.2.5 Format Delayed Data											
1.3 Data Distribution	2	4	Y		Y	Y		6	6	A	A
1.3.1 Preprocessing				Y			Y				
1.3.2 Data Capture				Y			Y				
1.3.3 Routing and Transmission											
1.3.4 Quality Verification											
1.4 Manage Deliverable Customer Data	2	4	Y		Y	Y		6	6	A	A
1.4.1 Customer Data Interface Mgt											
1.4.2 Customer Data Capture											
1.4.3 Customer Data Handling											
1.4.4 Ancillary Data Acquisition	4	6									
1.4.5 Level 0 Customer Data Processing											
1.4.6 Customer Data Accounting	3	6									
1.4.7 Routing and Transmission											
1.4.8 Payload and Core Coordination Monitor											
1.5 Manage Deliverable Core Data				Y				6	6	A	A
1.5.1 Core Data Interface Management	2	4				Y					
1.5.2 Core Data Capture	2	4				Y					
1.5.3 Data Extraction	2	4				Y					
1.5.4 Displays and Controls	3	5				Y					
1.5.5 Engineering Data Analysis	4	5									
1.5.6 Core Data Accounting	4	4									
2.0 Manage Customer/Operator Supplied Data											
2.1 Validate Payload Commands Data	2	4	Y		Y	Y		0,6	0,8	A	A
2.2 Check Payload Command Restriction/Constraint	2	4	Y	Y	Y	Y		0,6	0,6	A	A
2.3 Validate Core Commands/Data	3	5	Y		Y		Y	0,6	0,8	A	A
2.3.1 Authorize Operator											
2.3.2 Authorize Operation				Y			Y				
2.4 Provide Ancillary Data	3	5	Y		Y	Y		0	0	A	A
2.5 Support Customer System Operation								0	0		
2.5.1 Customer Data Processing	2	4	Y	Y	Y	Y	Y			A,I	A,I
2.5.2 Customer Payload Operations	2	4	Y	Y		Y				A,I	A,I

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

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SSDS FUNCTION LIST	ALLOCATION CRITERIA C1	C2	C3	C4	C5	C6	C7	DECISIONS: ALLOCATION IOC	ALLOCATION GROWTH	AUTOMATION IOC	AUTOMATION GROWTH
2.5.3 Support OTV Operations				Y	Y	Y		0	0		
2.5.3.1 OTV Servicing	3	4								A	A
2.5.3.2 OTV Checkout & Diagnostics	3	5								A	A
2.5.3.3 OTV Deployment/Retrieval	2	3								I	I
2.5.3.4 OTV Operation	2	4						0,6	0,6	I	I
2.5.3.5 OTV Status Report	2	4								A	A
2.5.4 Support OMV Operations			Y			Y	Y	0	0		
2.5.4.1 OMV Servicing	3	4			Y					A	A
2.5.4.2 OMV Checkout & Diagnostics	3	5			Y					A	A
2.5.4.3 OMV Deployment/Retrieval	2	3		Y						I	I
2.5.4.4 Remote Operations Control	1	3								I	I
2.5.4.5 OMV Operation	2	3						0,6	0,6	I	I
2.5.4.6 OMV Status Report	2	4		Y	Y			0,6	0,6	A	A
2.5.5 Customer Payload Checkout/Service	3	4			Y				0	A	A
2.6 SSPE Checkout and Servicing	3	4	Y	Y	Y	Y	Y	0	0	A	A
3.0 Schedule and Execute Operations											
3.1 Develop Recurring Operations Masters	4	5	Y		Y	Y		6	6	I	I
3.1.1 Develop Normal Day Payload Operations											
3.1.2 Develop Normal Day Space Station Operations											
3.1.3 Identify Potential Conflicts											
3.1.4 Develop Major Event Payload Operations											
3.2 Develop Short Term Schedules			Y			Y		6	6	I	I
3.2.1 Confirm Payload and Core Schedules	3	5		Y			Y				
3.2.2 Incorporate New/Revised Operations	3	5									
3.2.3 Check for Conflicts	2	4		Y			Y				
3.2.4 Check for Facilities Capabilities	2	4			Y	Y				A	A
3.2.5 Resolve Conflicts	2	4									
3.2.6 Check Unresolved, Restricted/Constrained Commands	2	4									
3.2.7 Maintain Short Term Schedules	2	4									
3.3 Develop Operating Events Schedule				Y				0	0		
3.3.1 Time Tag Operations	2	3	Y		Y	Y				A	A
3.3.2 Check Restricted/Constrained Real Time Commands	2	4	Y		Y	Y		0,6	0,6	A	A
3.3.3 Maintain Operating Events Schedule	3	4	Y			Y				I	I
3.3.4 Adjust for Unscheduled Mode Changes	2	4	Y							I	I
3.4 Sequence Operations			Y		Y	Y		0	0	A	A
3.4.1 Sequence Payload Operations	3	4									
3.4.2 Sequence Core System Operations	2	2		Y			Y				
3.4.3 Command Schedules Mode Changes	2	3									

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

SSDS FUNCTION LIST	C1	C2	C3	C4	C5	C6	C7	ALLOCATION IOC	ALLOCATION GROWTH	AUTOMATION IOC	AUTOMATION GROWTH
	ALLOCATION CRITERIA							DECISIONS			
4.0 Operate Core Systems											
4.1 Operate GN&C System											
4.1.1 Navigation			Y					O	O	A	A
4.1.1.1 Space Station State/Orbit Determ.	1	2		Y	Y	Y		O,G	O,G		
4.1.1.2 Constellation State/Orbit Determin.	1	2		Y	Y	Y					
4.1.1.3 Determine Ephemerides (Sun, Moon, etc.)	2	4									
4.1.1.4 Attitude Determination	2	4			Y						
4.1.1.5 Navigation State Propagation	1	2		Y	Y		Y				
4.1.1.6 Device Management	1	2			Y						
4.1.1.7 Command Interface Processing	3	4						O,G	O,G	I	I
4.1.2 Guidance			Y		Y			O	O	A	A
4.1.2.1 Reboost/Reentry Targetting	1	2		Y			Y	O,G	O,G		
4.1.2.2 Maneuver Coordination	1	2		Y							
4.1.2.3 Collision Check	1	2		Y			Y				
4.1.2.4 Reboost/Maneuver	4	5		Y			Y				
4.1.2.5 Tether Control	3	5		Y			Y				
4.1.2.6 Determine Pointing Mount Controls	3	4		Y							
4.1.2.7 Device Management	3	4									
4.1.2.8 Command Interface Processing	2	2						O,G	O,G		
4.1.3 Attitude Control			Y		Y			O,G	O,G	A	A
4.1.3.1 Control Attitude and Translation	1	1		Y		Y					
4.1.3.2 Effector Control	1	1		Y		Y					
4.1.3.3 Momentum Mgmt	3	4		Y		Y					
4.1.3.4 Pointing Mount Control	1	2		Y		Y					
4.1.3.5 Device Mgmt	1	2									
4.1.3.6 Cmd I/F Processing	3	4									
4.1.4 Traffic Control			Y		Y			O	O	A	A
4.1.4.1 Compute/Propagate Constellation Rel. State	1	2		Y			Y				
4.1.4.2 Manage Constellation Orbit Maneuvers	1	2		Y			Y				
4.1.4.3 Schedule Deployment/Rendezvous	3	5		Y							
4.1.4.4 Manage Rendezvous	1	2		Y			Y				
4.1.4.5 Target Collision Avoidance	3	2		Y			Y	O,G	O,G		
4.1.4.6 Cmd I/F Processing	1	2		Y				O,G	O,G		
4.1.5 Tracking			Y		Y			O	O		
4.1.5.1 Long Range Object Tracking	3	4								A	A
4.1.5.2 Proximity Tracking	2	2		Y						A	A
4.1.5.3 Object Catalog Maintenance	3	4								A	A
4.1.5.4 Tracking Data Conditioning	2	2								A	A
4.1.5.5 Device Mgmt	3	4								I	I
4.1.5.6 Cmd I/F Processing	1	2						O,G	O,G	I	I
4.1.6 Time and Frequency Management			Y	Y	Y	Y	Y	O	O	A,I	A,I
4.1.6.1 Time Source Mgmt	1	4									
4.1.6.2 Time Update	2	4									
4.1.6.3 Frequency Source Management	1	4									
4.1.6.4 Device Mgmt	3	5									
4.1.6.5 Cmd I/F Processing	3	5						O,G	O,G	A	

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

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SSDS FUNCTION LIST	ALLOCATION CRITERIA C1	C2	C3	C4	C5	C6	C7	DECISIONS: ALLOCATION IOC	ALLOCATION GROWTH	AUTOMATION IOC	AUTOMATION GROWTH
4.2 Operate Non-GN&C Core Systems											
4.2.1 Operate Power System			Y					O	O	A	A
4.2.1.1 Evaluate Array Performance	4	6			Y	Y					
4.2.1.2 Configure Power Distribution	1	4		Y	Y	Y	Y				
4.2.1.3 Power Source Mgmt	1	3		Y	Y	Y					
4.2.1.4 Array Deployment	3	4			Y	Y					
4.2.1.5 Project Energy Available	4	6			Y	Y					
4.2.1.6 Device Mgmt	3	2			Y	Y					
4.2.1.7 Cmmd I/F Processing	3	4		Y		Y		O,S	O,S	I	I
4.2.2 Operate Thermal Control System			Y	Y	Y	Y		O	O	A	A
4.2.2.1 Manage Thermal Load	2	2									
4.2.2.2 Device Mgmt	3	2									
4.2.2.3 Project Thermal Load Capacity Available	3	2									
4.2.2.4 Command I/F Processing	3	5	Y	Y				O,S	O,S	I	I
4.2.3 Structures & Mechanism Support	1	1	Y	Y	Y	Y	Y	O	O	A,I	A,I
4.2.3.1 Mechanism Control Safety											
4.2.3.2 MRMS Operations											
4.2.3.3 Manage Docking/Berthing											
4.2.3.4 Device Mgmt											
4.2.3.5 Cmmd I/F Processing						Y		O,S	O,S	I	I
4.2.4 ECLSS Operation			Y		Y	Y		O	O	A	A
4.2.4.1 Control Atmospheric Pressure and Composition	3	1		Y							
4.2.4.2 Control Temperature, Humidity	3	1		Y							
4.2.4.3 Potable Water Mgmt	3	1		Y							
4.2.4.4 Grey Water Mgmt	3	4		Y							
4.2.4.5 Fire Detection and Control	2	1		Y							
4.2.4.6 Device Mgmt	3	1									
4.2.4.7 Cmmd I/F Processing	3	5		Y		Y		O,S	O,S	I	I
4.2.5 Communication			Y	Y	Y	Y	Y	O	O		
4.2.5.1 Communication Network Control	1	4		Y						A,I,M	A,I,M
4.2.5.2 Communication Equipment Control	1	4								A,I,M	A,I,M
4.2.5.3 Communication Equipment Status Monitoring	3	5								A	A
4.2.5.4 Failure Detection/Recovery	3	5		Y			Y			A,I	A,I
4.2.5.5 Command Processing	2	4		Y			Y	O,S	O,S	A	A
4.2.5.6 Communication Interface Control	3	4		Y						A	A
4.2.5.7 Telemetry Control	3	5		Y						A	A
4.3 Support Flight Crew Activities											
4.3.1 Health Maintenance	4	5	Y			Y		O	O	I	I
4.3.1.1 Crew Physiological Monitoring				Y			Y				
4.3.1.2 Medical Diagnostics Support				Y			Y	O,S	O,S		
4.3.1.3 Treatment Support				Y			Y	O,S	O,S		
4.3.1.4 Nutrition Analyses				Y							
4.3.1.5 Exercise Planner				Y							
4.3.1.6 Physiological Data Transformation and Analysis											
4.3.1.7 Cmmd I/F Processing	3	2		Y			Y	O,S	O,S		

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

SSDS FUNCTION LIST				ALLOCATION CRITERIA						DECISIONS			
										ALLOCATION		AUTOMATION	
		C1	C2	C3	C4	C5	C6	C7	IOC	GROWTH	IOC	GROWTH
4.3.2	Space Station Safety	1	1	Y					O	O	A	A
	4.3.2.1 Caution & Warning				Y	Y	Y	Y	O,G	O,G		
	4.3.2.2 Abnormal and Emergency Procedures				Y	Y	Y	Y	O,G	O,G		
	4.3.2.3 Automatic Control Processing				Y	Y	Y	Y	O	O		
	4.3.2.4 Cmmd I/F Processing								O,G	O,G	M	M
4.3.3	Habitability			Y					O	O		
	4.3.3.1 Recreation Services	4	5				Y				M	M
	4.3.3.2 Crew/Ground Communications	4	5				Y				M	M
	4.3.3.3 Cmmd I/F Processing	3	5								I	I
4.3.4	EVA Support								O	O		
	4.3.4.1 EMU Contamination Control	3	3				Y				I	I
	4.3.4.2 EMU Monitor and Maintenance	4	5			Y	Y				A	A
	4.3.4.3 MMU Monitor and Maintenance	4	5			Y	Y				A	A
	4.3.4.4 Safety Interlock Monitor & Control	1	1		Y	Y	Y				A	A
	4.3.4.5 EVA Real Time Monitor & Control	3	5		Y	Y	Y		O,G	O,G	A	A
	4.3.4.6 EVA Visual Information	3	5		Y		Y				I	I
	4.3.4.7 Airlock Atmospheric Pressure and Composition Control	1	5			Y	Y				A	A
	4.3.4.8 Airlock Temperature and Humidity Control	1	5			Y	Y				A	A
	4.3.4.9 Device Mgmt	3	2		Y	Y	Y				A	A
	4.3.4.10 Cmmd I/F Processing	3	4	Y	Y		Y	Y	O,G	O,G	I	I
4.3.5	Operations & Procedure Support			Y			Y		O	O	I	I
	4.3.5.1 Maintenance and Repair Procedures	3	3									
	4.3.5.2 Operations Procedures	1	2									
	4.3.5.3 General Data Processing Support	4	5									
	4.3.5.4 General Purpose Programming Language	4	5		Y			Y				
4.4	Provide Customer Avionics Services											
4.4.1	GN&C Services	3	5	Y					O	O		
	4.4.1.1 Gnd Track Determination				Y	Y	Y				A,I	A,I
	4.4.1.2 Magnetic Field Determination					Y	Y				A	A
	4.4.1.3 Pallet Coarse Pointing					Y	Y				A,I	A,I
	4.4.1.4 Relative Alignment Determination				Y	Y	Y				A,I	A,I
4.4.2	Contamination Control	3	4	Y		Y	Y		O	O	A	A
	4.4.2.1 Venting Effects Determination											
	4.4.2.2 Environmental Monitor											
4.4.3	Tracking Services	3	3	Y		Y	Y		O	O	A,I	A,I
4.5	Monitor and Status System								O,G	O,G		
4.5.1	Monitor Core Systems Status	3	3		Y	Y	Y	Y			A	
4.5.2	Monitor Customer Systems Status	3	5			Y	Y				A	
4.5.3	Mass Properties Configuration Update	3	3	Y		Y	Y		G	G	A	
4.5.4	Diagnostics Support	3	5	Y	Y	Y	Y		G	O,G	A	A
	4.5.4.1 Fault Analysis				Y			Y				
	4.5.4.2 Fault Correction											
	4.5.4.3 Trend Analysis											
4.5.5	System Test and Evaluation	3	5		Y	Y	Y		O	O	A	A
4.5.6	Command Interface Processing	3	3	Y			Y		O,G	O,G	I	I

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

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SSDS FUNCTION LIST	C1	C2	C3	C4	C5	C6	C7	Allocation IOC	Allocation GROWTH	Automation IOC	Automation GROWTH
	ALLOCATION CRITERIA							DECISIONS			
5.0 Manage Facilities and Resources											
5.1 Manage Flight System Facilities			Y					O	O		
5.1.1 Flight Data Base Management				Y							
5.1.1.1 Update/Access Synch	3	4			Y	Y				A,I	A,I
5.1.1.2 Data File Mgmt	3	4			Y	Y		O,G	O,G	A	A
5.1.1.3 Mass Memory Resource Mgmt	4	4		Y	Y	Y	Y			A	A
5.1.1.4 Archival Storage	4	4		Y	Y	Y	Y			A,I	A,I
5.1.1.5 Device Mgmt	3	4		Y	Y	Y	Y			A,I	A,I
5.1.1.6 Cmmd I/F Processing	3	4		Y		Y	Y	O,G	O,G	I	I
5.1.2 Flight Resource Mgmt								O	O		
5.1.2.1 Load Scheduling	3	5				Y				I	I
5.1.2.2 System Executive	2	2			Y					A	A
5.1.2.3 Initialization & Config Control	2	4		Y	Y	Y	Y			A,I,M	A,I,M
5.1.2.4 Configure Data Processing Equipment	3	3		Y	Y	Y	Y			A,I,M	A,I,M
5.1.2.5 Facility Status	3	4			Y	Y				A,I	A,I
5.1.2.6 Reconfigure/Disconnect Payloads and Core Systems	1	3		Y	Y	Y	Y			A,I	A,I
5.1.2.7 Device Mgmt	3	4		Y		Y	Y			I	I
5.1.2.8 Cmmd I/F Processing	1	5		Y	Y	Y	Y	O,G	O,G	A,I	A,I
5.1.3 Displays & Controls								O	O		
5.1.3.1 Device Mgmt	3	5			Y	Y				A,I	A,I
5.1.3.2 Cmmd I/F Processing	3	5				Y				I	I
5.2 Manage Ground System Facilities	3	4	Y		Y	Y		G	G	A	A
5.2.1 Interface Management											
5.2.2 Schedule/Status Compare											
5.2.3 Generate Ground Configuration											
5.2.4 Ground Status Database Management											
5.2.5 Displays and Controls											
6.0 Develop, Simulate, Integrate and Train	4	5									
6.1 Interpret Model Requests			Y					G	G	I	I
6.2 Develop Communications Model Configuration			Y					G	G	A	A
6.3 Simulate Space Station System Communication Elements			Y					G	G	A,I	A,I
6.4 Develop Hardware Integration Configuration			Y					G	G	A	A
6.5 Simulate Space Station Elements								G	G	A,I	A,I
6.6 Develop Software Integration Configuration			Y					G	G	A	A
6.7 Simulate Space Station Processors			Y					G	G	A,I	A,I
6.8 Conduct Training								G	G		
6.8.1 Define Training Plan	4	5			Y	Y				A	A
6.8.2 Define Training Script	4	5			Y	Y				A	A
6.8.3 Define Model Requirements	4	5			Y	Y				A	A
6.8.4 Configure Simulation	3	5	Y		Y	Y				A	A
6.8.5 Conduct Training Exercise			Y					O,G	O,G	I	I
6.8.6 Evaluate Operator Performance			Y								
6.8.7 Maintain Operator Training Status	4	5	Y		Y	Y				A	A

Figure 5. SSDS Function Allocation/Automation Criteria and Decisions

SSDS FUNCTION LIST	ALLOCATION CRITERIA							DECISIONS			
								ALLOCATION		AUTOMATION	
	C1	C2	C3	C4	C5	C6	C7	IOC	GROWTH	IOC	GROWTH
6.9 Develop Software	3	5	Y			Y		G	G	I,M	I,M
6.9.1 Configuration Control and Management Support											
6.9.2 Requirement Analysis and Generation Tools											
6.9.3 Design and Code Generation											
6.9.4 Build and Delivery											
6.9.5 Testing and Analysis											
6.9.6 Documentation											
6.9.7 Communication											
6.9.8 Reconfiguration Data Management											
7.0 Support Space Station Program											
7.1 Maintain Integrated Logistics Plan	4	5	y			Y		G	G	I	I
7.1.1 Analyze System Performance											
7.1.2 Determine Effects On Integrated Plan											
7.1.3 Analyze Affected Plans											
7.1.4 Analyze Impact of Program Changes											
7.2 Log Customer Usage of System	4	5	Y		Y	Y		G	G	A	A
7.3 Maintain Technical Documentation	4	5	Y			Y		G	G	I	I
7.3.1 Analyze System Operation						Y				I	I
7.3.2 Update Technical Documents						Y				I	I
7.3.3 Analyze Program Changes					Y	Y				A	A
7.3.4 Transmit Procedures					Y	Y				A,I	A,I
7.4 Control Inventories	4	5	Y					G	G		
7.4.1 Monitor Customer Inventories					Y	Y				A	A
7.4.2 Monitor Station Inventories					Y	Y				A,I	A,I
7.4.3 Monitor Ground Facility Inventories					Y	Y				A	A
7.5 Configuration Management	4	5	Y		Y	Y		G	G	A	A

Figure 5. SSDS Function Allocation/Automation Criteria and Decision

SPACE SHUTTLE TO SPACE STATION SOFTWARE TRANSPORTABILITY TRADE STUDY

1.0 INTRODUCTION

This trade study provides a rough first-cut estimate of (1) the current size of the space shuttle software in the NASA Mission Support Directorate, (2) the amount of this software which might be transported, either whole or in part, to the Space Station Program and (3) the value of the transportable software.

1.1 BACKGROUND

The space shuttle software (and systems) environment is depicted in Figure 1.1.1. There are two Flight Planning "systems" used to develop requirements and to support the verification of project software. The production planning system provides flight specific data to the control center, the spacecraft system and the crew trainers. Through integrated simulations, the control center, the trainer and the spacecraft system mutually perform a validation function. These five systems are very well coordinated, but they are also very independent. Although there is some compatible hardware among the systems, there is a minimal amount of common software (in the planning systems). Additionally, the software development techniques employed are personalized for each system. The division responsible for the software is indicated in each box in Figure 1.1.1.

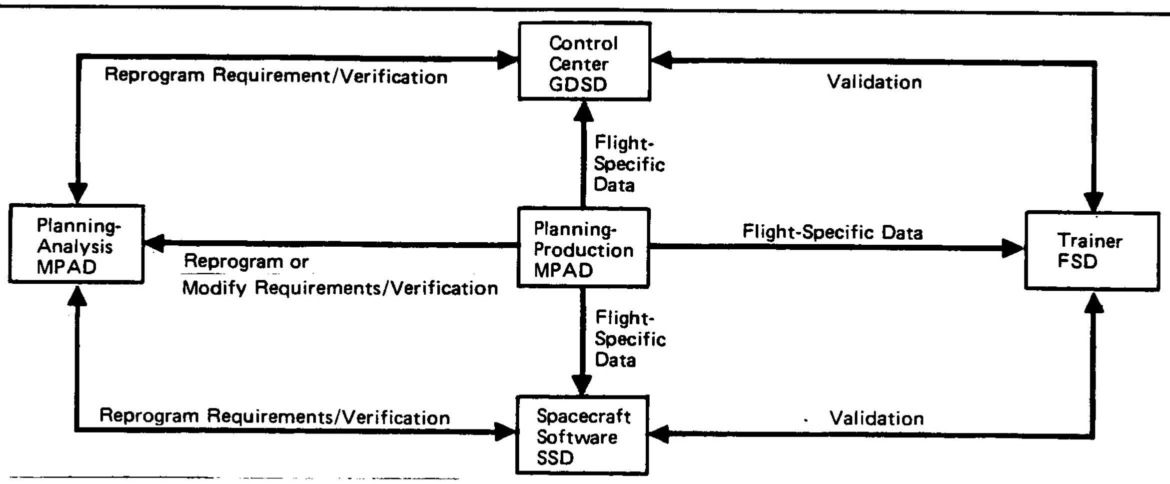


Figure 1.1.1. Space Shuttle Software Groups

Further characteristics of the five systems are provided in Figure 1.1.2. The column designated controls illustrates to some degree the personalized development techniques used for each system.

The amount of software in the Directorate is summarized in Figure 1.1.3. Data has not been gathered for the data bases and program products which support the space shuttle and are the responsibility of the Directorate. Program design language (PDL) and prologue comments are excluded from the sizing data in the figure; thus, what is provided represents executable code. This sizing data was obtained from each project at a level of detail as low as 100 source lines of code (SLOC). In some cases, comments were estimated based upon a simple count and then deleted at the summary level. The picture presented by this data - a lot of software spread throughout the Directorate - is correct even if some of the individual sizes are wrong by 10% or even 20%. This data does not include the cumulative amount of all software that was developed and later deleted or modified through scrubs; rather, it represents the size of the software in the Directorate <u>today</u>. In the form presented, the software has been summarized in categories which generally represent the complexity (or degree of difficulty in the development process) of the software. For example, operating system mods and system services are more difficult to develop and maintain than are support and utility software.

Throughout this study, all size and productivity data have been adjusted to reflect executable code only. Comparisons of the data presented here with other published data should be aware of a possible difference because of this convention.

1.2 ISSUES

The following issues are addressed in this trade study:

1.2.1 SOFTWARE COST MODEL

A model will be developed - based on space shuttle project experience - to estimate the development, maintenance and 10 year life cycle cost (LCC) of a large software system. The model will be used to extrapolate an upper bound

	Systems	Function	Controls
Planning - Analysis	Desk Top Computers Personal Computers Bench Models on Univac	Experiment Design Analyze	Easily Changeable No Configuration Control No Formal Testing
Trainer	SMS	Crew Training	Configuration Management Little Formal Testing Lengthy Change Interval
Planning - Production	Subsystem X Subsystem Y Ascent Design Descent Design	Conceptual and Detailed Flight Planning	Configuration Management Moderate Formal Testing Lengthy Change Interval
Control Center	MOC POCC	Mission Ground Support	Configuration Management Extensive Formal Testing Lengthy Change Interval
Spacecraft Software	Onboard Software SPF	Shuttle Control & Software Development	Configuration Management Maximum Formal Testing Lengthy Change Interval

Figure 1.1.2: Space Shuttle Software Characteristics

Software System		KSLOC*	Totals
Control Center	Operating System Mods	127	
	MOC - Real Time	1,106	
	- Support	738	
	TPC - Real Time	90	
	- Support	206	
	POCC	427	2,694
Planning	Analysis	1,377	
	Production	747	2,124
Trainer	Operating System Mods	28	
	Real Time	539	
	Offline Support	360	
	Utilities	2,101	3,028
Spacecraft	FLT - System Services	60	
	- Applications	330	
	SPF - Simulation	520	
	- Utilities	470	
	- Preprocessors	200	1,580
			9,426

*Thousands of source lines of code - PDL and prologue comments excluded

Figure 1.1.3: Current Space Shuttle Software Size

for the cost incurred by not transporting software between the space shuttle and space station projects.

1.2.2 VALUE OF CURRENT SHUTTLE SOFTWARE

For cost comparisons, a reference value in manyears (MY) of work will be established for the current space shuttle software system.

1.2.3 SIZE OF TRANSPORTABLE CODE

An estimate will be made of the size - in thousands of source lines of code (KSLOC) - of the software developed for the space shuttle which might be transported, either whole or in part, to the Space Station Program (SSP).

1.2.4 VALUE OF TRANSPORTABLE CODE

The software cost model will be used to estimate the value (again, in manyears of work) of the potentially transportable code.

1.3 TRADE STUDY CRITERIA

The following criteria are used to evaluate the options for each of the trade study issues.

1.3.1 GENERIC CRITERIA

Five generic criteria are common to all trade studies:

1.3.1.1 COST

DEVELOPMENT (NON-RECURRING): This is the cost to select, transfer, build and test the first working system.

MAINTENANCE (RECURRING): This is the cost to maintain the working system, upgrade the software to satisfy evolving requirements, train new programmers and provide user assistance.

LIFE CYCLE (NON-RECURRING AND RECURRING): This is the sum of the development and maintenance costs over a 10 year period.

1.3.1.2 RISK

DEVELOPMENT (LANGUAGE INSERTION, DESIGN DIFFICULTY): There is some uncertainty about the ease with which software modules and portions of modules coded in many different languages can be embedded into an ADA (or some other language) environment. The ADA-to-transported module interface may present unique design problems.

MAINTENANCE (RECONFIGURATION, COST/SCHEDULE, SKILL LEVELS): Multi-language systems are always more difficult to maintain than single-language systems. Reconfiguration and upgrades to satisfy new requirements are always slower (costlier) and incur more risk when a system is coded in more than one language. Programmers who must work in several languages are seldom as proficient in any of the languages as programmers who use one language exclusively. Programmer training is also more expensive.

1.3.1.3 PERFORMANCE

SYSTEM SPEED: This is a measure of the speed at which a software system performs the task assigned to it. If the interfaces between languages in a multi-language system are not clean, then processing speed will suffer.

SYSTEM SIZE: This is a measure of the core memory consumption of a system. Multi-language systems require language interfaces which make them somewhat larger than single-language systems.

1.3.1.4 STANDARDIZATION/COMMONALITY

Standard design and programming practices ensure consistent system response. Sections of transported code which do not meet Space Station Project standards will have to be modified to satisfy the standards.

1.3.1.5 GROWTH/TECHNOLOGY INSERTION

All software systems evolve over time as new requirements surface and new technology and algorithms become available. In a multi-language system, it may prove difficult to insert new technology into modules coded in some of the languages.

1.3.2 TRADE STUDY UNIQUE CRITERIA

To be a candidate for transfer, a space shuttle software function must correspond to a similar Space Station Project function proposed in Section 6.0 (Onboard SSDS Definition), 7.0 (Ground SSDS Definition) or 8.0 (System Development Concepts) of Reference 3. Each transferred function must be capable of being embedded in a new host dedicated to space station processing.

1.4 APPLICABLE OPTION PAPERS

Several Task 2 option papers are applicable to this trade study. The total list is:

- -1.4.1 Advanced Algorithums
- -1.4.2 High Order Language
- -2.2.2 Autonomy/Automation
- -2.2.5.1 Payload/SSDS Interface Options
- -2.5.1 Space Communications
- -2.5.2 Wide Area Communications
- -3.1 Standardization/Commonality Options
- -3.2 System Management
- -3.5.2 Software Development

The prime option paper among these is 2.5.2, Wide Area Networks. The others are of lesser interest.

1.5 ALTERNATIVES

This trade study assumes that all space shuttle software transported to the Space Station Project will be embedded in one or more software systems dedicated entirely to space station processing. No other options are considered. Under this constraint, three software re-location alternatives are available:

1.5.1 RE-CODE ALL TRANSPORTABLE SOFTWARE

With this alternative, all transportable software would be re-coded in a single (project) language - probably ADA. This alternative would be taken if no significant cost advantage could be obtained by transporting software for any of the five software systems in Figure 1.1.1.

1.5.2 RE-CODE SOME TRANSPORTABLE SOFTWARE

For this option to be chosen, a cost advantage must be available for transporting software for at least one (but not all) of the five shuttle software systems. The remaining transportable software would be re-coded in the project language.

1.5.3 TRANSPORT ALL TRANSPORTABLE SOFTWARE

This alternative would be taken if a significant cost advantage could be obtained by transporting software for each of the five shuttle software systems.

2.0 METHODOLOGY

The numbers cited in this study for the amount of transportable code are rough engineering estimates. Data for the current sizes of the Control Center, Flight planning, Trainer and Spacecraft Software systems is taken from Reference 1. Software cost models are taken from Reference 2. The Space Station project software environment is assumed to be the one proposed in

Sections 6.0 (Onboard SSDS Definition), 7.0 (Ground SSDS Definition) and 8.0 (System Development Concepts) in Reference 3.

The following example illustrates the process used for obtaining estimates of the transportable SPF simulator software. It is fairly typical of the first-cut estimation processes used for all of the software subsystems.

Initially, two assumptions are made about the space station simulator environment:

1. The current SPF simulator languages (primarily HLAL, PL/1 and Fortran) can be maintained in the SSE.

2. PL/1, Fortran and HLAL generated object code can be embedded within the primary SSE language environment (Ada).

The following multiplication factors are applied to the current SLOC count for each SPF simulator function transferred to the SSE:

Environment Models	1.0
Hardware Models	0.8
Control/Initialization Programs	0.7
Monitor Programs	0.9
Math Utility Programs	1.0

The simulator functions assumed to be re-locatable (along with SLOC counts of the transported code) are summarized below. Partial lists of SPF modules containing re-locatable code are included as some of the functions.

Control/Initialization (Transported Code: 2361 SLOC)

- Provide phased execution of the models within the math model task.
- Math model initialization.
- Onorbit step-ahead
- SMDLEORB

Math Utilities (Transported Code: 630 SLOC)

- Matrix utilities.
- Random number generator.

Monitor (Transported Code: 3300 SLOC)

- Log model data.
- Compute orbital elements for multiple vehicles.
- SMDLER10

Equations of Motion (Transported Code: 3430 SLOC)

- High rate Taylor series predictor/corrector for vehicle state.
- Low rate precision integrator (Pines' Method).
- Gravity model (J_{22} + precision).
- Sun, Moon, gravity gradient torque influences.
- SMDLEEOM, SMDLEPRE, SMDLEPLE, SMDLEGRA, SMDLEGGT

Mass Properties (Transported Code: 4122 SLOC)

- Mass, center of gravity, inertia computation for multiple elements.
- RCS moment arms.
- RMS/payload effects.
- SMDLEMS1, SMDEMS2

Target State Vectors (Transported Code: 442 SLOC)

- Provide equations of motion translational states for up to five free-flyers.
- SMDLETGT

RMS (Transported Code: 8850 SLOC)

- Provide rigid and flex arm dynamics.
- SMDLSRMS, SMDLSDRS

RCS (Transported Code: 2645 SLOC)

- Force/moment due to RCS firings.
- Jet/vehicle impingement interaction.
- SMDLGRC1, SMDLGRC2

Star Tracker (Transported Code: 1005 SLOC)

- Shuttle star tracker hardware.
- Earth occultation/sun effects.
- SMLDGSTU

Simulation Macros (Transported Code: 50,000 SLOC)

Simulation Control (Transported Code: 60,000 SLOC)

The amount of SPF simulator software estimated at first cut to be transportable to the SSE is 136,785 SLOC (see Figure 3.3.1).

3.0 RESULTS

3.1 SOFTWARE COST MODEL

Sections 3.1.1 through 3.2.4 define a model (taken from Reference 2) for estimating software development, maintenance and life cycle costs for the space shuttle and space station programs. The model is used in Sections 3.2 and 3.4 to estimate the value of the current space shuttle software system and the value of the shuttle software which may be transported to the Space Station Program.

3.1.1 SPACE SHUTTLE PRODUCTIVITY EXPERIENCE

Data for the productivity experienced on the shuttle project (Figure 3.1.1.1) was gathered from the Directorate Divisions, Branches and contractors and normalized for a work month of 20 days. Where possible (SPF, flight software and MOC), the data was also adjusted to include all cost elements of the project (system analysis, quality assurance, project management, etc.). There was a general lack of data for the productivity experienced with the trainer - the 120 SLOC/MM composite was estimated by the FSD Office. This data inherently represents the cost of developing software in the peculiar environment of each system - the state of the requirements, the amount of verification, the skills of the work force, etc.

Software System		SLOC/MM
MOC	Operating System Mods	160
	Applications	190
	Support	250
Flight Planning	Executive	240
	Applications	200
	Analysis	240
Trainer	Operating Systems Mods	120?
	Applications	120?
	Offline Support	120?
	Utilities	120?
TPC	Operating System Mods	?
	Real Time	198
	Support	214
SPF	Simulation	169
	Preprocessors	278
Flight Software	HAL	78
	Assembler	51

Figure 3.1.1.1: Space Shuttle Productivity Experience

3.1.2 DEVELOPMENT COST MODEL

The development cost model partitions the software into categories based upon complexity, amount of testing employed, status of requirements, etc. Size (KSLOC) and productivity (KSLOC/MM) estimates are developed for each category, and then the total development cost is obtained by adding the separate costs:

$$\mathrm{COST} = \frac{\mathrm{SIZE}_1}{\mathrm{PRODUCTIVITY}_1} + \frac{\mathrm{SIZE}_2}{\mathrm{PRODUCTIVITY}_2} + \ldots$$

The productivities selected for the model are shown in Figure 3.1.2.1. For the control center, MOC and TPC productivities are assumed to be the same (the bulk of the software resides in the MOC and the data in the figure is obtained from MOC experience). The production planning productivity is decreased to account for common support functions which are not included in the shuttle productivity experience. The productivities chosen for the trainer reflect a comparison of trainer software with spacecraft software with a consideration of less definition in requirements. The productivities for the spacecraft software are rounded-off values of the shuttle experience.

3.1.3 MAINTENANCE COST MODEL

The maintenance cost model (Figure 3.1.3.1) assumes that software maintenance costs represent between 100% and 150% of development costs - equivalent to between 50% and 60% of the total 10 year life cycle cost. To determine the number of programmers required to maintain the software, an estimate is made for the number of source lines of code that one programmer can maintain in each software subsystem. These estimates are chosen (based upon shuttle experience) to provide a conservative (low) count for the required number of programmers to ensure that only valid conclusions are developed from the results.

3.1.4 LIFE CYCLE COST MODEL

The 10 year life cycle cost (LCC) model simply assumes that the life cycle cost is equal to the sum of the development and maintenance costs for each software subsystem:

$$\text{LIFE CYCLE COST}_n = \text{DEVELOPMENT COST}_n + \text{MAINTENANCE COST}_n$$

The total life cycle cost for the project is equal to the sum of the separate life cycle costs:

$$\text{TOTAL LIFE CYCLE COST} = \text{LIFE CYCLE COST}_1 + \text{LIFE CYCLE COST}_2 + \ldots$$

Software System		Productivity (SLOC/MM)
Control Center	Operating System Mods	160
	MOC - Real Time	190
	- Support	250
	TPC - Real Time	190
	- Support	250
	POCC	190
Planning	Analysis	240
	Production	180
Trainer	Operating System Mods	30
	Real Time	50
	Offline Support	80
	Utilities	300
Spacecraft	FLT - System Services	50
	- Applications	80
	SPF - Simulation	170
	- Utilities	280
	- Preprocessors	280

Figure 3.1.2.1: Development Model

Software System		Maintenance Costs (% of Dev Cost)	Maintenance Level* (KSLOC/Programmer)
Control Center	Operation System Mods	150	20**
	MOC - Real Time	150	30
	- Support	100	40
	TPC - Real Time	150	30
	- Support	100	40
	POCC	150	30
Planning	Analysis	100	50
	Production	150	30
Trainer	Operating System Mods	150	20**
	Real Time	150	15
	Offline Support	100	40
	Utilities	100	50
Spacecraft	FLT - System Services	125	6
	- Applications	125	10
	SPF - Simulation	150	30
	- Utilities	100	30
	- Preprocessors	100	30

* Not total support level
** Assumes a base operating system support cadre

Figure 3.1.3.1: Maintenance Model

3.2 VALUE OF CURRENT SHUTTLE SOFTWARE

Using the software cost model developed in Sections 3.1 – 3.1.4, the total value of the current space shuttle project software is estimated to be 10,787 manyears (Figure 3.2.1). The development cost accounts for 4,750 manyears of the total.

3.3 SIZE OF TRANSPORTABLE CODE

Estimates of the amount of software which can be transported, either whole or in part, from the space shuttle to the space station project are given in Figure 3.3.1. The granularity of the numbers in the figure is 1 KSLOC; if the total amount of transportable code in a software subsystem rounds off to less than 1 KSLOC, then it is considered to be too low for comparison and will not show up in the figure.

Additionally, it has been assumed that the onboard flight software (both system services and applications) will be re-coded entirely in a new (non-HAL) language. None of it is therefore considered to be transportable.

Finally, no data was collected for the Flight Planning and Trainer systems. Thus, the total amount of re-locatable software is probably larger than the 1,520 KSLOC shown in the figure.

3.4 VALUE OF TRANSPORTABLE CODE

Again, using the software cost model developed in Sections 3.1 – 3.1.4, the 10 year life cycle cost of the transportable Control Center and Spacecraft (SPF) code is estimated to be 1,537 manyears (Figure 3.4.1). the relocatable Control Center software accounts for 1,337 manyears; the SPF software, for the remaining 200 manyears. No figures are currently available for the Flight Planning and Trainer systems. The development cost of the transportable Control Center and Spacecraft code is estimated to be 643 manyears.

Software System	Dev. Cost (MY)	Maint. Cost (MY)	LCC (10 Yrs) (MY)
Control Center	1,093	1,481	2,574
Planning - Analysis	478	478	956
Planning - Production	346	519	865
Trainer	1,935	2,423	4,358
Spacecraft	898	1,136	2,034
Totals	4,750	6,037	10,787

Figure 3.2.1: Value of Current Space Shuttle Software

Software System		KSLOC*	Totals
Control Center	Operating System Mods	100	
	MOC - Real time	870	
	- Support	378	
	TPC - Real Time	0	
	- Support	0	
	POCC	0	1,328
Planning	Analysis	**	
	Production	**	**
Trainer	Operating System Mods	**	
	Real Time	**	
	Offline Support	**	
	Utilities	**	**
Spacecraft	FLT - System Services	0	
	- Applications	0	
	SPF - Simulation	137	
	- Utilities	55	
	- Preprocessors	0	192
			1,520***

* Thousands of source lines of code - PDL and Prologue comments excluded.
** Data currently unavailable.
*** Total does not include Planning and Trainer transportable software.

Figure 3.3.1: Space Shuttle Transportable Software Size

Software System	Dev. Cost (MY)	Maint. Cost (MY)	LCC (10 Yrs) (MY)
Control Center	560	777	1,337
Planning - Analysis	*	*	*
Planning - Production	*	*	*
Trainer	*	*	*
Spacecraft	83	117	200
Totals	643**	894**	1,537**

* Data currently unavailable.
** Totals do not include Planning and Trainer transportable software.

Figure 3.4.1: Value of Space Shuttle Transportable Software

4.0 CONCLUSIONS/RECOMMENDATIONS

4.1 CONCLUSIONS

The space shuttle software environment is composed of the five systems shown in Figure 1.1.1. The current aggregate size of the systems is 9,426 KSLOC, representing a 10 year life cycle cost of 10,787 MY and a development cost of 4,750 MY.

For two of the five systems (specifically, the Control Center and Spacecraft systems), the amount of space shuttle software which might be transported to the Space Station Project is estimated to be 1,520 KSLOC, representing a development cost of 643 MY. No estimates have been made for the transportable software in the other three systems.

The 643 MY figure for the Control Center and Spacecraft systems should <u>not</u> be regarded as the amount of effort which would be saved by transporting software from these systems. Background language interface and multiple language maintenance costs must be subtracted from the figure to obtain the true savings. If these costs are estimated to be 20 percent of the development cost (equivalent to 129 MY), then 514 MY of effort will be saved by transporting code.

4.2 RECOMMENDATIONS

The preliminary recommendation is to transport space shuttle software to the Space Station Project. The recommendation is based upon first-cut analyses of both economic and technical issues (refer to Sections 4.2.1 and 4.2.2) associated with the problem.

4.2.1 ECONOMIC ISSUES

The following tasks were performed to determine the economic feasibility of transporting space shuttle software to the Space Station Project:

1. The total amount of space shuttle software in the NASA Mission Support Directorate was estimated and divided into logically separate groups. This task was initially accomplished in Reference 1 and was presented here again.

2. Based on the space shuttle experience, a model was developed for estimating the cost (in manyears of effort) of large manned spaceflight software systems. The model was able to differentiate between development (short term), maintenance (long term) and life cycle (total) costs. This task was accomplished in Reference 2 and was also presented here again.

3. The Space Station Project software environment was predicted. This was done in Reference 3.

4. With the data from the previous task, the amount of space shuttle software which could be transported to the Space Station Project was estimated for two of the five software groups defined in Section 1.1 (the Control Center and Spacecraft software).

5. Using the software cost model, the value of the transportable software was determined for the Control Center and Spacecraft groups.

6. The size of the interface software required to embed the transported software into a background project language was estimated.

7. Using the software cost model, the cost of the interface software was determined.

8. The minimum cost advantage (in manyears of effort) required to justify transporting space shuttle software was arbitrarily established as one manyear - that is, if one manyear of effort could be shown to be saved by transporting software, then the decision would be made to transport it.

9. The interface software cost (obtained in step 7) was subtracted from the transportable software value (obtained in step 5). The result was larger than the minimum required cost advantage (determined in step 8), and it was therefore determined to be economically feasible to transport the software.

10. If the result of the subtraction performed in step 9 had been uncomfortably close to the minimum required cost advantage (step 8), then at least one more iteration would have been preformed on steps 1 through 9. In particular, an enhancement in knowledge of the predicted software environment (step 3) might greatly improve the estimate of transportable code made in step 4.

Each of the tasks listed above was performed on a software group basis (refer to Figure 1.1.1). Separate decisions on transportability were made for each group.

4.2.2 TECHNICAL ISSUES

The following tasks were performed to determine the technical feasibility of transporting space shuttle software to the Space Station Project:

1. The ADA-to-transported module interface was investigated at a first-cut level. No major design problems were identified.

2. System speed and size penalties for transported software were assessed (refer to Section 1.3.1.3). The software transported into the shuttle project SPF simulator was used as a yardstick.

In addition, the following technical issues should be considered as the Space Station Project requirements evolve:

1. The host computer hardware environment should be investigated. Any changes to the transported code (I/O, etc.) driven by the host hardware should be factored into the economic feasibility study in Section 4.2.1.

2. An estimate of the new technology likely to be inserted into the Space Station Project should be made. Any transported modules coded in languages which cannot support the new technology should be identified and candidate work-arounds should be proposed and evaluated.

5.0 REFERENCES

1. Kidd, R. H., "Space Shuttle Software Commonality," IBM FSD, 1984.

2. Bunde, M., et al, "Space Station Operations Management Task Overview," IBM FSD, 1984.

3. "Space Station Data System Analysis/Architecture Study, Task 4 – System Definition Report," McDonnell Douglas Astronautics Company, MDC H1942, May 1985.

SYSTEM NETWORK TOPOLOGY TRADE STUDY

1.0 TRADE STUDY DEFINITION

1.1 BACKGROUND AND REQUIREMENTS

The objective of the network topology trade study is to identify the nodes and links which will comprise the network. A large number of requirements drive this definition. Every function identified in Task 1 of the SSDS study must be allocated to a system node. Any communications between functions allocated to different nodes must be serviced by system links. In addition, mission requirements have been derived from the Langley data base. The key requirements provided here are peak data rates, average data rates and allowable delays. In cases where allowable delays are zero, links may be sized to meet the peaks. Otherwise, links may be sized to meet the averages.

1.2 ISSUES TO BE ADDRESSED

This trade study focuses on two issues. The first is the basic network configuration. The identification of the nodes, links, and traffic is determined. The second issue is the optimum architecture to manage payload data. The analysis of the payload data management is divided into a preliminary analysis and a detailed analysis. The preliminary analysis is described in Section 2 of this trade study report. The detailed cost analysis is described in Section 3. Section 4 provides a description of other issues involved and provides the recommended topology.

1.3 CRITERIA

The primary criteria used to compare alternative architectures is cost. For the preliminary analysis, a normalized annual cost is derived. For the detailed analysis, the cost is divided into fixed costs and recurring costs.

A number of other criteria were also used to select a topology. As a result of the detailed cost analysis, it was determined that the cost differentials between the topologies were significant, but not overwhelming. The other criteria, and how they apply to the topology options, are described in Section 4. These include growth potential, risk, and overall considerations of the entire Space Station system.

1.4 APPLICABLE OPTIONS

The following options white papers were used to provide information for this study:

Space Communications (2.5.1)
Wide Area Communications (2.5.2)
Mass Storage (1.1)
Standards (3.1)

1.5 ALTERNATIVE CONFIGURATIONS

For the preliminary analysis, three topologies were considered (see Section 2.5). These were:

1) Centralized Processing at White Sands
2) Centralized Processing at Goddard
3) Distributed Processing

Of these three, the second option was discarded due to extremely high communications cost. For the detailed analysis, a new option was considered which was a combination of the two. This "hybrid" option, provides for distributed processing of high rate data and centralized processing of low rate data. The three options studied in detail are described in Section 3.2.

2.0 PRELIMINARY ANALYSIS

The objective of the Space Station Network Topology trade study is to identify the nodes and links which will comprise the Space Station Network. This will be determined by the system traffic requirements, and also some key design decisions. Some of these design issues will be analyzed as part of this trade study, while others will be discussed in terms of assumptions which are made and the effects of these assumptions.

Sections 2.1 through 2.3 identify the network elements and the network traffic. Section 2.1 describes the network nodes. These correspond to the Space Station Program elements which were defined in Task 1 of the SSDS study. Section 2.2 delineates all of the traffic which flows through the Space Station Network. This is done on a logical node-to-node basis. Section 2.3 discusses the characteristics of the links which will be available to carry this traffic.

Assumptions as to which physical links carry which logical traffic for all traffic are presented in Section 2.4. This table includes the results which specify the payload data path. It is recognized that the transport and processing of payload data will be a major topology driver. Options for the routing and processing of payload data are presented in Section 2.5. The system performance for each option is predicted using a computer simulation. The model which has been developed for this purpose is discussed in Section 2.6. This model also takes into account the effects of 1, 2, or 3 TDRSS single access channels.

Section 2.7 discusses cost assumptions which were used in assessing the various options. It is important to note here that the network nodes are SSDS elements, while the network links are SSIS services. It is outside of the scope of the SSDS study to analyze in detail the implementation of the transportation service (DOMSAT vs. Fiber Optics). It is, however, necessary to assign some type of cost to the communications service in order to perform a meaningful trade (bandwidth vs. buffer). Thus, a simple measure of communications cost will be derived and presented.

Given the simulation results and the cost assumptions system elements, each option is costed and the results of the preliminary analysis are described in Section 2.8.

2.1 Space Station Network Nodes

The nodes of the Space Station Network coincide with the Space Station Program Elements as identified in task 1 report. In the case of elements for which the multiplicity is to be determined, a strawman baseline has been developed. Brief descriptions of the nodes along with rationale for the baseline are provided in this section.

2.1.1 The Space Station

The Space Station node services as a communications concentration point for multiple payloads, core subsystems, and other identified elements. These include the OMV, OTV, free fliers; with options for STS and the COP. The Space Station receives data from the payloads and constellation elements, and relays the data to the ground, together with core systems data. The Space Station routes the commands and data for payloads, core systems, and other SSPE's. The Space Station Network must support real time transmission of operating data and commands, near real time transmission of quicklook data, and delayed transmission of bulk commands and data. Real time operations of the payloads require limited two-way data relay, including audio and video links.

2.1.2 Polar Orbiting Platform(s)

The POP is a polar platform in sun-synchronous orbit which will be used primarily for earth and atmospheric observation. POP has no interaction with the Space Station on orbit, but will share some ground data handling facilities.

The Space Station Network must support real time transmission of operations data and commands for the POP payloads as well as near real time transmission of quicklook science data and delayed transmission of stored commands and data. Based on the current mission model, it is assumed that there will be two POPS at IOC, three at growth.

2.1.3 Co-Orbiting Platform(s)

For the purpose of this study, it is assumed that the COP maintains continuous line-of-sight with the space station. It is recognized that this may not be true for certain mission scenarios. The use of a COP-SS link will be assumed for both COP-ground and ground-COP traffic. The space station network must support real time transmission of operations data and commands for the COP and COP payloads as well as near real time transmission of quicklook science data and delayed transmission of stored commands and data.

2.1.4 Data Handling Center (DHC)

The Data Handling Center serves as the space/ground gateway between the TDRSS Ground Terminals (WSGT and NGT) and the ground- to-ground data distribution network. It receives and buffers data, and routes virtual channels onto/from the ground netowrk, and handles uplink logon and authorization checking. The DHC is located at White Sands.

2.1.5 Space Station Operations Control Center (SSOCC)

The SSOCC is responsible for ground support of the Space Station Operations and Control. The SSOC receives core data and passes it through to the Engineering Data Center (EDC). It is also the origin of SS core commands.

2.1.6 POP Control Center (POPCC)

The POP Control Center is responsible for ground support of the platform operations and control. It is assumed that there will be one POPCC for each POP.

2.1.7 COP Control Center (COPCC)

The COP Control Center is responsible for the ground support of the platform operations and control.

2.1.8 Payload Operations and Control Centers (POCC's)

The POCC's are responsible for the ground support of payload operations and control. This will include interactive real time commanding and quicklook analysis on science data. The POCC's will coordinate operations with the related platform control center.

2.1.9 Level Zero Processing Facilities (LZPF)

The LZPF's are responsible for science data processing and short term (seven day storage). The LZPF will support quicklook analysis at the POCC's.

Based on analysis of the Langley Data Base, six candidate locations have been defined for LZPF's. These are:

LZPF 1 – Goddard Space Flight Center (GSFC)
LZPF 2 – Marshall Space Flight Center (MSFC)
LZPF 3 – Johnson Space Flight Center (JSC)
LZPF 4 – Jet Propulsion Laboratory (JPL)
LZPF 5 – Lewis Research Center (LERC)
LZPF 6 – Langley Research Center (LARC)

It should be noted that LZPF's will be used to support Regional Data Centers (RDC's). These are SSIS elements which perform higher level payload data processing.

2.1.10 Engineering Data Center

The Engineering Data Center provides archival storage of Space Station engineering data. This center will support program and customer requests for Space Station historical data.

2.1.11 Customer Facilities

Commercial customers, as well as some others, will have their own facilities for payload operation and control and data reception, archiving, and analysis. A customer facility may be connected directly to the Space Station Network, to a Regional Data Center or to a POCC. When tied to the RDC, the customer facility can utilize the support services available at the RDC.

2.1.12 Ground Services Center (GSC)

The Ground Services Center (GSC) provides communication and common resource coordination for the ground system. It serves to coordinate the scheduling of the communication and ground facility resources shared among the Space Station, COP, and POP operations control centers. The GSC also collects status information from these facilities (outages, data quality monitoring, etc.) and prepares reports of this information for both customers and the OCCs.

2.2 The Traffic

The traffic model used for this study is composed of two parts. Section 2.2.1 describes the mission traffic model, which was derived using the Langley data base. Section 2.2.2 describes the other traffic.

2.2.1 Mission Traffic Analysis

The mission traffic data base was initiated with a set of 74 missions. Twenty of these missions contained incomplete or questional entries. These are listed in Figure 2.2-1.

Additionally, the following changes were incorporated in the data.

1. The downlink data rate for TDMX2542 was set to 10 Kbps.
2. The source for SAAX0220 was set to POP2.
3. The source for SAAX0225 was set to POP2.

The remaining payloads were analyzed for each of the years described in the data base. Figure 2.2-2 illustrates the total of average downlink data rates for the active payloads by years.

PAGE NO. 00001
04/17/85

REPORT FOR DOWNLINK FREQ = 0 OR UL RATE = 25000 kbps

MISSION #	SOURCE	DOWNLINK DATA RATE	DOWNLINK FREQ/DAY	DOWNLINK DUR HRS	UPLINK DATA RATE
SAAX0202	PP1	0.00	0.00	0.00	0.00
SAAX0215	PP1	10.00	0.00	24.00	0.01
COMM1304	SS	0.00	0.00	0.00	0.00
SAAX0021	SS	100.00	0.00	24.00	1.00
SAAX0115	SS	0.00	0.00	0.00	0.00
SAAX0201	SS	0.00	0.00	0.00	0.00
SAAX0302	SS	50.00	0.00	0.00	2.00
SAAX0303	SS	30.00	0.00	12.00	30.00
SAAX0307	SS	50.00	0.00	24.00	2.00
SAAX0308	SS	1.00	0.00	0.00	0.00
SAAX0502	SS	56.00	0.00	0.00	56.00
TDMX2061	SS	1000.00	1.00	0.10	25000.00
TDMX2072	SS	0.00	0.00	0.00	0.00
TDMX2421	SS	20.00	0.00	0.00	2.00
COMM1309	SS	0.00	0.00	0.00	0.00
SAAX0116	SS	0.00	0.00	0.00	0.00
SAAX0117	SS	0.00	0.00	0.00	0.00
SAAX0304	SS	2.00	0.00	24.00	0.10
SAAX0306	SS	1.00	0.00	24.00	0.10
TDMX2064	SS	1000.00	1.00	0.10	25000.00

Excluded Missions
Figure 2.2-1

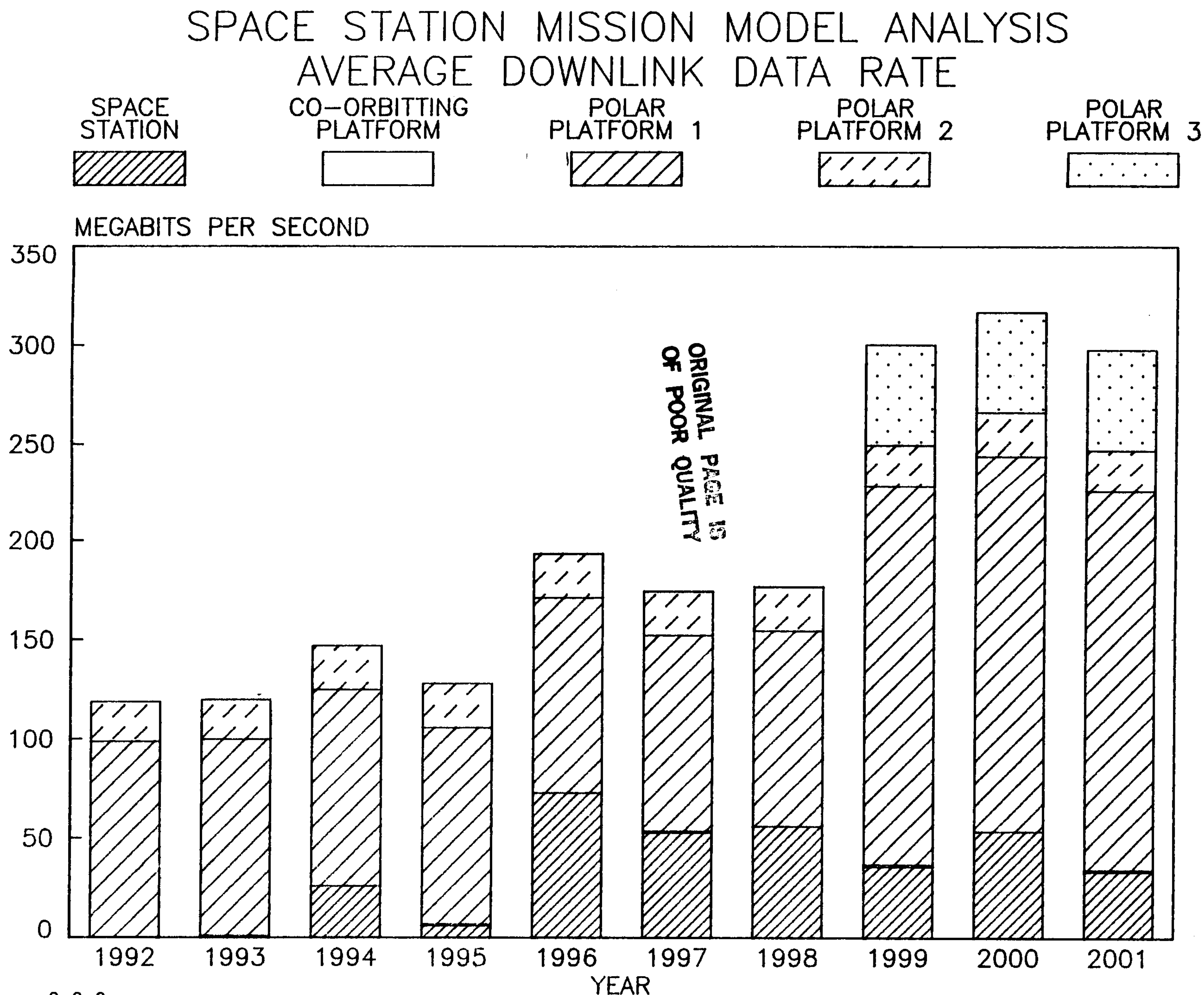


Figure 2.2-2

JRS 3/30/85

The traffic was further analyzed for the years 1994 and 1997. Figures 2.2-3 and 2.2-4 show the mission sets as well as the assumed data destination for 1994 and 1997. Figures 2.2-5 and 2.2-6 provide detailed downlink traffic characteristics for the two years by mission. Figures 2.2-7 and 2.2-8 provide point-to-point summaries of the average volumes. Figures 2.2-9 and 2.2-10 show the command uplink summaries, based on the assumption that the bulk of the commands originate at the RDC's. Figure 2.2-11 lists all of the video requirements.

2.2.2 Other Data

Figure 2.2-12 contains a summary of the other space station system traffic. The derivation of these numbers is provided here.

2.2.2.1 Space Station Core Engineering

It is assumed that core engineering data is generated at a rate of 256 Kbps (2 * Shuttle). All of this data is assumed to go to the SSOCC. This data, along with processed ancillary data, must then go to the engineering data center. It is assumed that the processed ancillary data (definitive orbit, attitude) will add 4 Kbps data to the traffic from the SSOCC to the EDC.

2.2.2.2 COP Core Engineering

It is assumed that COP core engineering data is generated at a rate of 64 Kbps (2* space telescope). COP core engineering data also goes to the EDC.

2.2.2.3 POP Core Engineering

It is assumed that POP Core Engineering data is generated at a rate of 64 Kbps per POP. (2* Space Telescope.) POP Core Engineering data also goes to and the EDC. Note that there are 2 POPS at "IOC", and three at "Growth."

2.2.2.4 Space Station Command Uplink

Space Station Commands go from the SSOCC to the Space Station. It is assumed that real time commands and stored program commands combine to generate a 4 Kbps stream. This is consistent with current shuttle command rates.

PAGE NO. 00001
04/17/85

SPACE STATION SOURCE/RDC REPORT

MISSION #	MISSION NAME	SOURCE	RDC
COMM1019	Stereo Imaging Spectrometer	PP1	GSFC
SAAX0208	Mod. Res. Imaging Spectrometer	PP1	GSFC
SAAX0209	High Res. Imaging Spect. (HIRIS)	PP1	GSFC
SAAX0210	High Res. Multifreq. MW Radiomet.	PP1	GSFC
SAAX0216	Earth Radiation Budget Exp-ERBE	PP1	GSFC
SAAX0228	Thermal IR Mapping Spectrometer	PP1	GSFC
SAAX0230	Fabry Perot Interferometer	PP1	GSFC
SAAX0238	NADIR Climate Interfer./Spectrom.	PP1	GSFC
SAAX0211	Laser Atmospheric Sounder and Alt.	PP2	GSFC
SAAX0213	Altimeter	PP2	GSFC
SAAX0214	Scatterometer	PP2	GSFC
SAAX0219	Environmental Monitors	PP2	GSFC
SAAX0220	Automated Data Collect./Loc. System	PP2	GSFC
SAAX0229	Cryogenic Interfer/Spectrom.	PP2	GSFC
SAAX0231	VIS/UV Spectrometer	PP2	GSFC
SAAX0232	Microwave Limb Sounder	PP2	GSFC
SAAX0234	Interferometer/Spectr./Upper Atm.	PP2	GSFC
SAAX0235	Upper Atm. IR Radiometer	PP2	GSFC
SAAX0212	Synthetic Aperature Radar	PP2	JPL
SAAX0005	Transition Radiation and Ion. Cal.	PP2	MSFC
COMM1014	Remote Sensing Test, Dev. and Verif.	SS	GSFC
COMM1202	EOS Production Units	SS	GSFC
SAAX0009	ASO I/POF	SS	GSFC
SAAX0207	Solar-Terrestrial Observatory	SS	GSFC
TDMX2542	Tethered Constellation	SS	GSFC
TDMX2441	Guided Wave Optics Data Sys. Expt.	SS	JPL
COMM1206	Biological Production Units	SS	JSC
TDMX2153	Solar Dynamic Power	SS	LEWIS
TDMX2311	Long-Term Cryogenic Fluid Storage	SS	LEWIS
COMM1201	Microgravity and Materials Proc. Fac.	SS	MSFC
COMM1203	ECG Production Units	SS	MSFC
COMM1204	Microgravity and Materials Process Fac.	SS	MSFC
SAAX0401	Microgravity and Mat. Proc. Fac. (MMPF)	SS	MSFC
SAAX0404	Microgravity and Mat. Proc. Fac. (MMPF)	SS	MSFC
TDMX2011	Spacecraft Materials and Coatings	SS	MSFC
TDMX2132	Advanced Radiator Concepts	SS	MSFC

Mission Source Destination 1994

Figure 2.2-3

C-2

PAGE NO. 00001
04/17/85

SPACE STATION SOURCE/RDC REPORT

MISSION #	MISSION NAME	SOURCE	RDC
SAAX0004	SIRTF Platform Mission	COP	GSFC
COMM1019	Stereo Imaging Spectrometer	PP1	GSFC
SAAX0208	Mod. Res. Imaging Spectrometer	PP1	GSFC
SAAX0209	High Res. Imaging Spect. (HIRIS)	PP1	GSFC
SAAX0210	High Res. Multifreq. MW Radiomet.	PP1	GSFC
SAAX0216	Earth Radiation Budget Exp-ERBE	PP1	GSFC
SAAX0228	Thermal IR Mapping Spectrometer	PP1	GSFC
SAAX0230	Fabry Perot Interferometer	PP1	GSFC
SAAX0238	NADIR Climate Interfer./Spectrom.	PP1	GSFC
SAAX0211	Laser Atmospheric Sounder and Alt.	PP2	GSFC
SAAX0213	Altimeter	PP2	GSFC
SAAX0214	Scatterometer	PP2	GSFC
SAAX0219	Environmental Monitors	PP2	GSFC
SAAX0220	Automated Data Collect./Loc. System	PP2	GSFC
SAAX0225	Solar-Terres. Polar Platform Exp.	PP2	GSFC
SAAX0229	Cryogenic Interfer/Spectrom.	PP2	GSFC
SAAX0231	VIS/UV Spectrometer	PP2	GSFC
SAAX0232	Microwave Limb Sounder	PP2	GSFC
SAAX0234	Interferometer/Spectr./Upper Atm.	PP2	GSFC
SAAX0235	Upper Atm. IR Radiometer	PP2	GSFC
SAAX0212	Synthetic Aperature Radar	PP2	JPL
SAAX0005	Transition Radiation and Ion. Cal.	PP2	MSFC
SAAX0233	Submillimeter Spectrometer	PP3	GSFC
SAAX0236	Doppler LIDAR	PP3	GSFC
SAAX0237	Differential Absorption LIDAR	PP3	GSFC
COMM1014	Remote Sensing Test, Dev. and Verif.	SS	GSFC
COMM1202	EOS Production Units	SS	GSFC
SAAX0011	ASO II/POF + SOT	SS	GSFC
TDMX2261	Sensor Systems Technology	SS	GSFC
COMM1206	Biological Production Units	SS	JSC
SAAX0227	Contained Plasma Experiment	SS	LANG
COMM1201	Microgravity and Materials Proc. Fac.	SS	MSFC
COMM1203	ECG Production Units	SS	MSFC
COMM1204	Microgravity and Materials Process Fac.	SS	MSFC
SAAX0401	Microgravity and Mat. Proc. Fac. (MMPF)	SS	MSFC
SAAX0404	Microgravity and Mat. Proc. Fac. (MMPF)	SS	MSFC
TDMX2011	Spacecraft Materials and Coatings	SS	MSFC
COMM1208	Crystal Production Units	SS	MSFC

Mission Source Destination 1997

Figure 2.2-4

PAGE NO. 00001
04/18/85

SPACE STATION POINT-TO-POINT DOWNLINK

SOURCE	RDC	MISSION #	DOWNLINK DATA RATE (kbps)	DOWNLINK FREQ/DAY	DOWNLINK DUR HRS	DOWNLINK AVG RATE
PP1	GSFC	COMM1019	200000.00	16.00	0.50	66666.666660
PP1	GSFC	SAAX0208	3000.00	7.00	0.50	437.499999
PP1	GSFC	SAAX0209	160000.00	16.00	0.25	26666.666650
PP1	GSFC	SAAX0210	50.00	1.00	24.00	50.000000
PP1	GSFC	SAAX0216	0.24	1.00	24.00	0.240000
PP1	GSFC	SAAX0228	30000.00	16.00	0.20	3999.999999
PP1	GSFC	SAAX0230	5.00	16.00	0.75	2.500000
PP1	GSFC	SAAX0238	30.00	1.00	24.00	30.000000
PP2	GSFC	SAAX0211	40.00	16.00	0.75	20.000000
PP2	GSFC	SAAX0213	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0214	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0219	2.50	0.10	24.00	0.250000
PP2	GSFC	SAAX0220	20.00	1.00	24.00	20.000000
PP2	GSFC	SAAX0229	10.00	16.00	0.75	5.000000
PP2	GSFC	SAAX0231	2000.00	1.00	24.00	2000.000000
PP2	GSFC	SAAX0232	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0234	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0235	20.00	1.00	24.00	20.000000
PP2	JPL	SAAX0212	300000.00	16.00	0.10	19999.999980
PP2	MSFC	SAAX0005	100.00	1.00	24.00	100.000000
SS	GSFC	COMM1014	300000.00	1.00	0.20	2499.999999
SS	GSFC	COMM1202	5.00	1.00	24.00	5.000000
SS	GSFC	SAAX0009	1400.00	16.00	1.00	933.333332
SS	GSFC	SAAX0207	10000.00	4.00	1.50	2500.000000
*SS	GSFC	TDMX2542(10)	10000.00	8.00	0.50	1666.666666
SS	JPL	TDMX2441	20.00	1.00	2.00	1.666666
SS	JSC	COMM1206	5.00	4.00	1.00	0.833333
SS	LEWIS	TDMX2153	10.00	1.00	0.10	0.041666
SS	LEWIS	TDMX2311	64.00	1.00	24.00	64.000000
SS	MSFC	COMM1201	50.00	4.00	1.00	8.333333
SS	MSFC	COMM1203	2.00	1.00	24.00	2.000000
SS	MSFC	COMM1204	50.00	4.00	1.00	8.333333
SS	MSFC	SAAX0401	50.00	1.00	24.00	50.000000
SS	MSFC	SAAX0404	50.00	1.00	24.00	50.000000
SS	MSFC	TDMX2011	2.00	1.00	0.25	0.020833
SS	MSFC	TDMX2132	4.00	1.00	0.10	0.016666
** TOTAL **						
			1017029.74			127849.068500

Downlink Traffic 1994 by Mission
Figure 2.2-5

PAGE NO. 00001
04/18/85

SPACE STATION POINT-TO-POINT DOWNLINK

SOURCE	RDC	MISSION #	DOWNLINK DATA RATE (kbps)	DOWNLINK FREQ/DAY	DOWNLINK DUR HRS	DOWNLINK AVG RATE
COP	GSFC	SAAX0004	1000.00	1.00	24.00	1000.000000
PP1	GSFC	COMM1019	200000.00	16.00	0.50	66666.666660
PP1	GSFC	SAAX0208	3000.00	7.00	0.50	437.499999
PP1	GSFC	SAAX0209	160000.00	16.00	0.25	26666.666650
PP1	GSFC	SAAX0210	50.00	1.00	24.00	50.000000
PP1	GSFC	SAAX0216	0.24	1.00	24.00	0.240000
PP1	GSFC	SAAX0228	30000.00	16.00	0.20	3999.999999
PP1	GSFC	SAAX0230	5.00	16.00	0.75	2.500000
PP1	GSFC	SAAX0238	30.00	1.00	24.00	30.000000
PP2	GSFC	SAAX0211	40.00	16.00	0.75	20.000000
PP2	GSFC	SAAX0213	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0214	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0219	2.50	0.10	24.00	0.250000
PP2	GSFC	SAAX0220	20.00	1.00	24.00	20.000000
PP2	GSFC	SAAX0225	2000.00	4.00	4.00	1333.333332
PP2	GSFC	SAAX0229	10.00	16.00	0.75	5.000000
PP2	GSFC	SAAX0231	2000.00	1.00	24.00	2000.000000
PP2	GSFC	SAAX0232	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0234	10.00	1.00	24.00	10.000000
PP2	GSFC	SAAX0235	20.00	1.00	24.00	20.000000
PP2	JPL	SAAX0212	300000.00	16.00	0.10	19999.999980
PP2	MSFC	SAAX0005	100.00	1.00	24.00	100.000000
PP3	GSFC	SAAX0233	3.00	1.00	24.00	3.000000
PP3	GSFC	SAAX0236	30.00	16.00	0.75	15.000000
PP3	GSFC	SAAX0237	10.00	16.00	0.75	5.000000
SS	GSFC	COMM1014	300000.00	1.00	0.20	2499.999999
SS	GSFC	COMM1202	5.00	1.00	24.00	5.000000
SS	GSFC	SAAX0011	50000.00	16.00	1.00	33333.333300
SS	GSFC	TDMX2261	10.00	1.00	4.00	1.666666
SS	JSC	COMM1206	5.00	4.00	1.00	0.833333
SS	LANG	SAAX0227	50000.00	1.00	8.00	16666.666660
SS	MSFC	COMM1201	50.00	4.00	1.00	8.333333
SS	MSFC	COMM1203	2.00	1.00	24.00	2.000000
SS	MSFC	COMM1204	50.00	4.00	1.00	8.333333
SS	MSFC	SAAX0401	50.00	1.00	24.00	50.000000
SS	MSFC	SAAX0404	50.00	1.00	24.00	50.000000
SS	MSFC	TDMX2011	2.00	1.00	0.25	0.020833
SS	MSFC	COMM1208	2.00	1.00	24.00	2.000000
** TOTAL **						
			1098586.74			175043.343600

Downlink Traffic 1997 by Mission
Figure 2.2-6

	GSFC	MSFC	JSC	JPL	LeRC	LRC	Total
SS	7605	119	1	2	64		7791
COP							
POP 1	97854						97854
POP 2	2105	100		20000			22205
POP 3							
Total	107564	219	1	20002	64		127850

Note: Units are kilobits per second

Figure 2.2-7. Downlink Point-to-Point Summary, 1994

	GSFC	MSFC	JSC	JPL	LeRC	LRC	Total
SS	35840	120	1			16667	52628
COP	1000						1000
POP 1	97854						97854
POP 2	3439	100		20000			23539
POP 3	23						23
Total	138156	220	1	20000		16667	175044

Note: Units are kilobits per second.

Figure 2.2-8. Downlink Point-to-Point Summary, 1997

	GSFC	MSFC	JSC	JPL	LeRC	LRC	Total
SS	800	2254	167	2	4		3227
COP							
POP 1	42						42
POP 2	394	8		21			423
POP 3							
Total	1236	2262	167	23	4		3692

Note: Units are bits per second

Figure 2.2-9. Uplink Point-to-Point Summary, 1994

	GSFC	MSFC	JSC	JPL	LeRC	LRC	Total
SS	733	2750	167			333	3983
COP	667						667
POP 1	42						42
POP 2	1061	8		21			1090
POP 3	19						19
Total	2522	2758	167	21		333	5801

Note: Units are bits per second

Figure 2.2-10. Uplink Point-to-Point Summary, 1997

PAGE NO. 00001
04/18/85

SPACE STATION POINT-TO-POINT VIDEO 1994

S/C	RDC	MISSION #	DOWNLINK VID RATE (kbps)	D/L VID FREQ	D/L VID DUR	UPLINK VID RATE (kbps)	U/L VID FREQ	U/L VID DUR
SS	GSFC	COMM1202	22000.00	1.00	0.50	0.00	0.00	0.00
SS	GSFC	SAAX0207	2.00	1.00	1.00	0.00	0.00	0.00
SS	GSFC	TDMX2542	12000.00	8.00	0.50	0.00	0.00	0.00
SS	JSC	COMM1206	22000.00	2.00	1.00	0.00	0.00	0.00
SS	LEWIS	TDMX2153	90.00	0.00	0.00	0.00	0.00	0.00
SS	MSFC	COMM1201	22000.00	2.00	1.00	22000.00	0.20	0.50
SS	MSFC	COMM1203	22000.00	0.10	0.10	0.00	0.00	0.00
SS	MSFC	COMM1204	22000.00	2.00	1.00	22000.00	0.20	0.50
SS	MSFC	TDMX2132	90.00	0.00	0.00	0.00	0.00	0.00

PAGE NO. 00001
04/18/85

SPACE STATION POINT-TO-POINT VIDEO 1997

S/C	RDC	MISSION #	DOWNLINK VID RATE (kbps)	D/L VID FREQ	D/L VID DUR	UPLINK VID RATE (kbps)	U/L VID FREQ	U/L VID DUR
PP2	GSFC	SAAX0225	2.00	0.00	0.00	0.00	0.00	0.00
SS	GSFC	COMM1202	22000.00	1.00	0.50	0.00	0.00	0.00
SS	JSC	COMM1206	22000.00	2.00	1.00	0.00	0.00	0.00
SS	LANG	SAAX0227	2.00	1.00	8.00	0.00	0.00	0.00
SS	MSFC	COMM1201	22000.00	2.00	1.00	22000.00	0.20	0.50
SS	MSFC	COMM1203	22000.00	0.10	0.10	0.00	0.00	0.00
SS	MSFC	COMM1204	22000.00	2.00	1.00	22000.00	0.20	0.50
SS	MSFC	COMM1208	22000.00	0.10	0.10	0.00	0.00	0.00

Payload Video Requirements
Figure 2.2-11

TYPE	FROM	TO	RATE	DUTY CYCLE	AVG RATE
SS CORE	SS	SSOCC	256.00	100.00	256.00
SS ANCIL	SS	EDC	260.00	100.00	260.00
COP CORE	COP	COPCC	64.00	100.00	64.00
COP ANCIL	COP	EDC	64.00	100.00	64.00
POP1 CORE	POP1	POPCC	64.00	100.00	64.00
POP1 ANCIL	POP1	EDC	64.00	100.00	64.00
POP2 CORE	POP2	POPCC	64.00	100.00	64.00
POP2 ANCIL	POP2	EDC	64.00	100.00	64.00
SS CMD	SSOCC	SS	4.00	100.00	4.00
SS DATA UP	SSOCC	SS	256.00	10.00	25.60
COP CMD	COPCC	COP	4.00	100.00	4.00
COP DATA UP	COPCC	COP	64.00	10.00	6.40
POP1 CMD	POPCC	POP1	4.00	100.00	4.00
POP2 CMD	POPCC	POP2	4.00	100.00	4.00
POP1 DATA UP	POPCC	POP1	64.00	10.00	6.40
POP2 DATA UP	POPCC	POP2	64.00	10.00	6.40
CORE HR VIDEO	SS	SSOCC	22000.00	100.00	22000.00
CORE LR VIDEO	SS	SSOCC	1544.00	100.00	1544.00
CORE AUDIO	SS	SSOCC	64.00	100.00	64.00
HR VIDEO	SSOCC	SS	22000.00	100.00	22000.00
LR VIDEO	SSOCC	SS	1544.00	100.00	1544.00
AUDIO	SSOCC	SS	64.00	100.00	64.00
SIM UP	DSIT	SS	5.00	5.00	0.25
SIM DOWN	SS	DSIT	1.00	5.00	0.01
ARCHIVE RETR	EDC	LZPFs	4.80	50.0	2.40
SCHEDULE COORD	GSC	ALL	4000.00	100.00	4000.00

Figure 2.2-12. Other Space Station Traffic Data Base

2.2.2.5 Space Station Data Uplink

The data uplink contains text, graphics, and data base loads. Currently, the shuttle 216 Kbps command format allows 128 Kbps for text and graphics. It is assumed that this traffic category will produce 256 Kbps with a ten percent duty cycle.

2.2.2.6 COP Command Uplink

COP commands go from the COPCC to the COP. It is assumed that real time commands and stored program commands combine to generate a 4 Kbps stream.

2.2.2.7 COP Data Uplink

Due to the fact that the COP is unmanned, it is assumed that the COP data uplink will be one-fourth of the Space Station Data Uplink.

2.2.2.8 POP Uplink Commands

POP commands go from the POPCC to the (each) POP. It is assumed that real time commands and stored program commands combine to generate one 4 Kbps stream (per). This is consistent with COP command assumptions.

2.2.2.9 POP Data Uplink

The data uplink assumptions for each POP are identical to the data uplink assumptions for the COP.

2.2.2.10 Space Station Core Video Downlink

It is assumed that there will be one downlink channel dedicated to 22 Mbps high resolution video and one dedicated downlink channel for 1.544 Mbps resolution video. This traffic goes from the space station to the SSOCC. This affects the network topology study because it utilizes TDRSS bandwidth which is thus unavailable for other traffic.

2.2.2.11 Space Station Core Video Uplink

It is assumed that all high resolution video uplink will be required for recreation, public relations, and training. This traffic is assumed to be 22 Mbps with a 5% duty cycle. It is also assumed that there will be one dedicated 56 Kbps low resolution video channel from the SSOCC and the space station. This affects the network topology study because it utilizes TDRSS bandwidth which is thus unavailable for other traffic.

2.2.2.12 Audio Traffic

It is assumed that there will be two bi-directional dedicated 32 Kbps audio channels between the SS and the SSOCC.

2.2.2.13 Core Archival Retrieval

It is assumed that each LZPF will generate enough requests for archived core ancillary data to require 4.8 Kbps of data with a 50% duty cycle.

2.2.2.14 Schedule Coordination

It is assumed that the GSC will require a continuous 4 Kbps stream to and from each ground SSPE, and the Space Station.

2.3 The Links

The links in the space station network are SSIS services. The objective of this study is to identify key performance requirements for these links. Section 2.3.1 discusses the assumptions for the space to ground relay service. Section 2.3.2 discusses the ground to ground links.

2.3.1 Space to Ground Links

It is assumed that the TDRS system will be the main space to ground relay service. This system provides multiple access S band service, and single access service which includes both K-band (KSA) and S-band (SSA).

It is assumed that Reed-Solomon encoding will be applied to the single access downlinks, and that the effective bandwidth is reduced by 10%. It is also assumed that each space node will have access to one S band multiple access link. Figure 2.3-1 shows the assumed TDRSS effective available uplink and downlink bandwidths. Note that the encoding overhead is symmetric.

For purposes of this study, it is assumed that the Space Station will act as an intermediate node for all COP traffic (if COP is in continual line-of-sight). This decision was made because the low volume of COP traffic in the mission set does not warrant the exclusive use of a TDRSS single access channel.

	Service		
	MA	SSA	KSA
Uplink	10 kbps	270 kbps	225 Mbps
Downlink	50 kbps	2.7 Mbps	270 Mbps

Note: Single-access channel includes Reed-Solomon encoding

Figure 2.3-1. TDRSS Effective Bandwidth

2.3.2 Ground-to-Ground Links

For purposes of this study, it is assumed that ground-to-ground links will be available between any two points at any rate.

2.4 Traffic Assignment

The traffic which was described in Section 2.2 must flow over the physical links which were described in Section 2.3. This is done in two steps. Assumptions are made for the assignment of the "other" traffic (Section 2.2.2). Given these assumptions, further analysis is performed for the payload downlink traffic. Note that the topology used to support payload uplink traffic is driven by command management philosophy, not traffic volume.

The traffic assignments for the traffic described in Section 2.2.2 are provided in Figure 2.4-1. The key in performing this assignment is that the end points of the combined physical links are the same as the end points of the logical traffic requirement. For example, Space Station core engineering data logically must go from the SS to the SSOCC. This is physically implemented with two links; SS-DHC, DHC-SSOCC.

2.5 Topology Options

For purposes of this study, it is assumed that all payload outputs are in the format of CCSDS packets. For the preliminary analysis, only high rate payloads are considered. The function of the ground facilities is to reconstruct the payload outputs and transport them to the customer; not necessarily in that order.

Figures 2.5-1 through 2.5-4 illustrate the four topology options for payload data transportation and processing. The key difference between the options is the location of the data set reconstruction, and the imposed communications requirements. The key issue here is the definition of data set reconstruction. In the mission data base, there is a field named "Duration." It is assumed that a data set is the output of the payload for the specified period of duration.

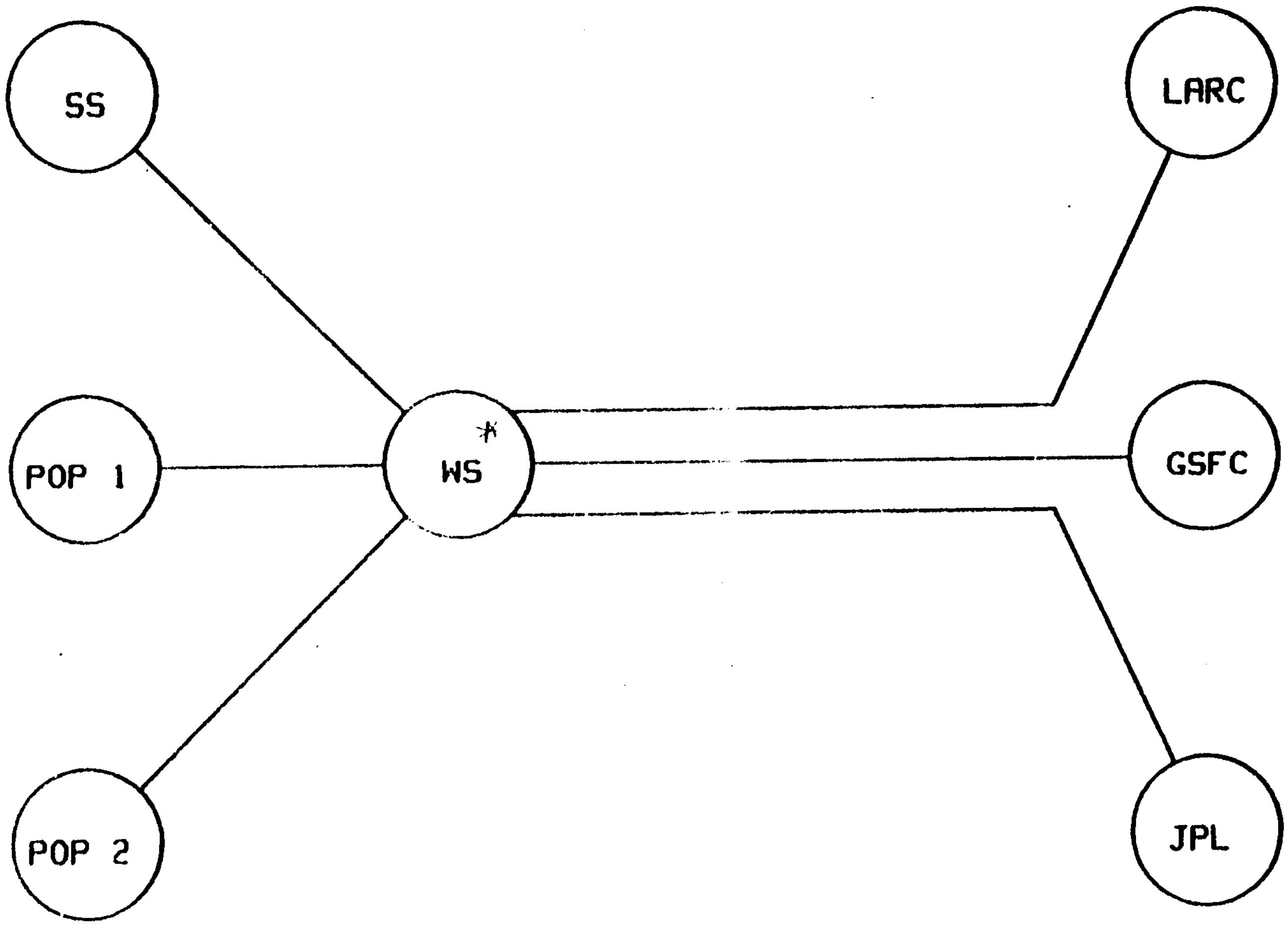
	TDRSS-SS KSA	TDRSS-SS SSA	SS-COP	TDRSS-POP KSA	TDRSS-POP SSA	DHC-SSOCC	DHC-COPCC	DHC-POPCC	DHC-POCC	DHC-LZPF	LZPF-POCC	LZPF-CUST	DHC-CUST	SSOCC-EDC	COPCC-EDC	POPCC-EDC	POCC-EDC	LZPF-EDC	DHC-EDC	CUST-EDC	GSC-DHC	GSC-POCC	GSC-LZPF	GSC-SSOCC	GSC-COPCC	GSC-POPCC
SS Core		X				X								X												
COP Core		X	X				X								X											
POP Core					X			X								X										
SS Cmd Up		X				X																				
SS Data Up		X				X																				
COP Cmd Up		X	X				X																			
COP Data Up		X	X				X																			
POP Cmd Up					X			X																		
POP Data Up					X			X																		
Archive Retrievals		X												X	X	X	X	X	X	X						
High-Rate Video Up	X					X			X					X												
High-Rate Video Down	X					X			X					X												
Low-Rate Video Up		X				X			X					X												
Low-Rate Video Down		X			X	X		X	X					X		X										
Audio Up		X				X			X					X												
Audio Down		X				X			X					X												
SS Payload Data	X									X	X	X														
SS Payload Eng Down		X								X	X	X														
SS Payload Cmd Up	X								X				X													
COP Payload Data	X		X							X	X	X														
COP Payload Eng Down		X	X							X	X	X														
COP Payload Cmd Up	X		X						X				X													
POP Payload Data				X						X	X	X														
POP Payload Eng Down					X					X	X	X														
POP Payload Cmd Up				X					X				X													
Schedule Coord		X			X																X	X	X	X	X	X

Figure 2.4.1. Traffic Link Assignments

Figure 2.5-5 shows a summary of the processing and communications requirements for each option.

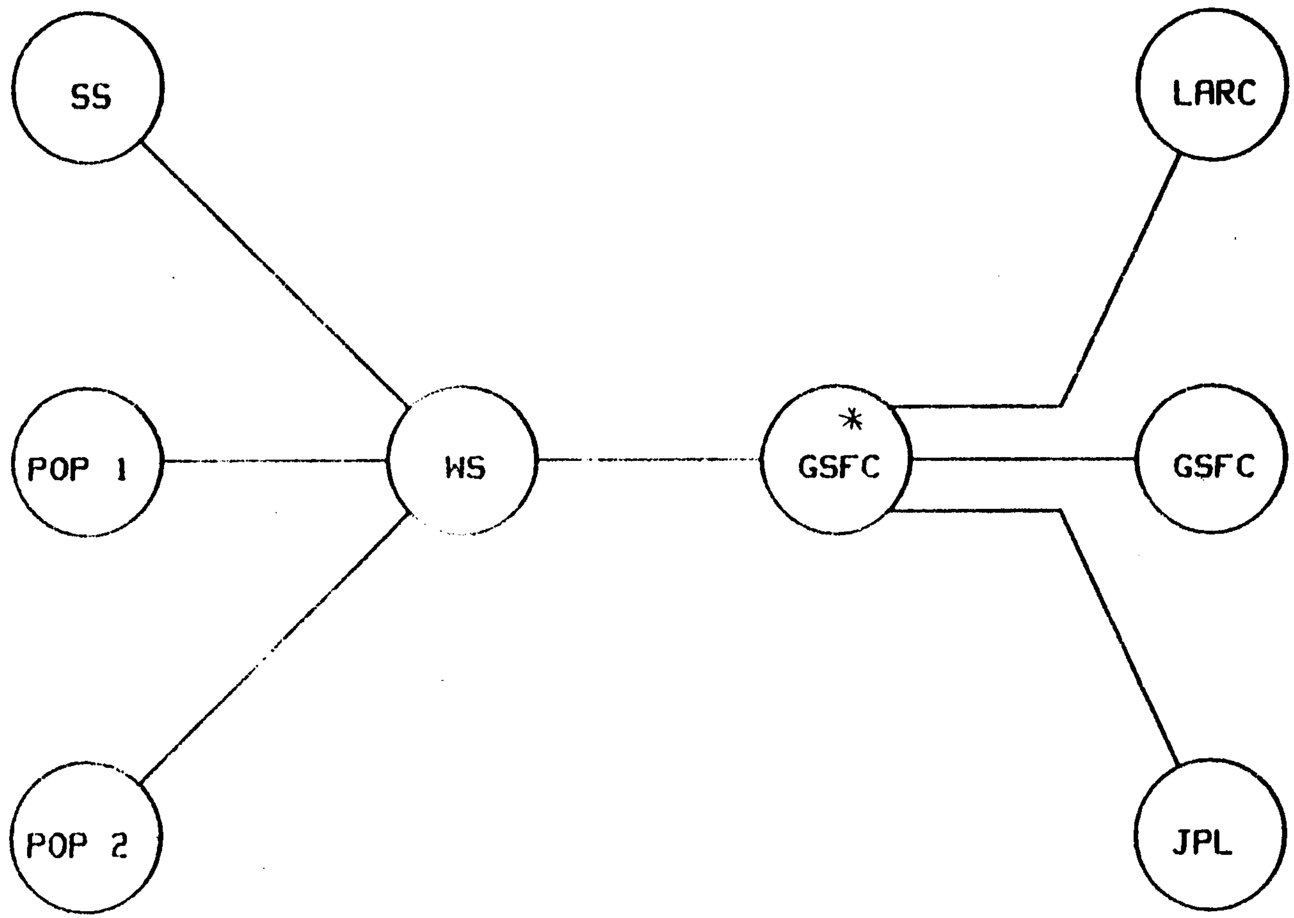
Option 1 provides for reconstruction of all data sets at White Sands. Once the data sets are reconstructed, they are then transmitted to their final destination.

Option 2 provides for the relay of all data from White Sands to Goddard Space Flight Center, where the data sets are reconstructed and transmitted to their final destination. The advantage of this approach is that similar processing and the associated expertise currently reside at Goddard. The disadvantage is that there is added communications cost for a WS- GSFC link. Most of the increased expense here is the transport of fill data.



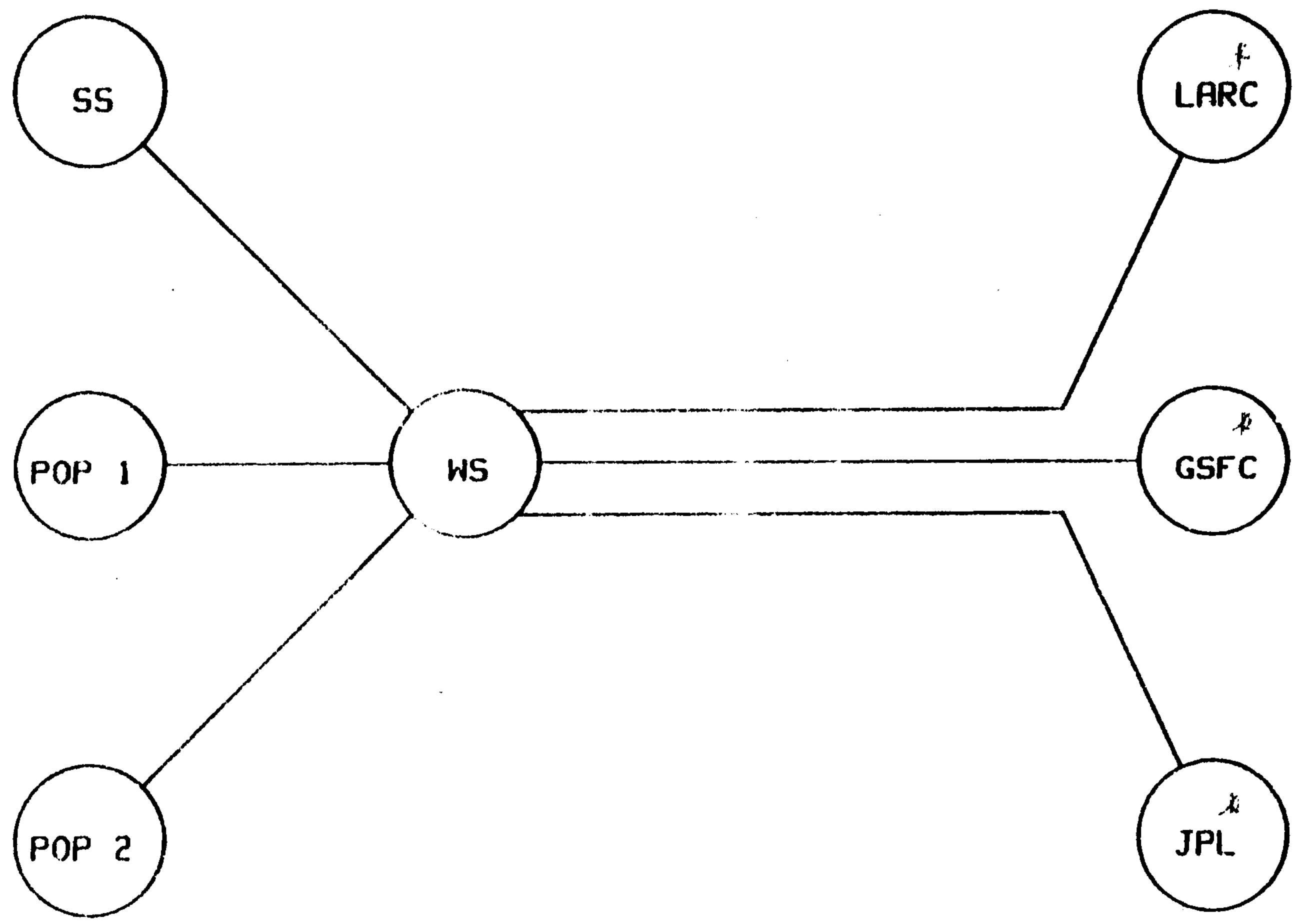
* DATA SET RECONSTRUCTION

Figure 2.5-1



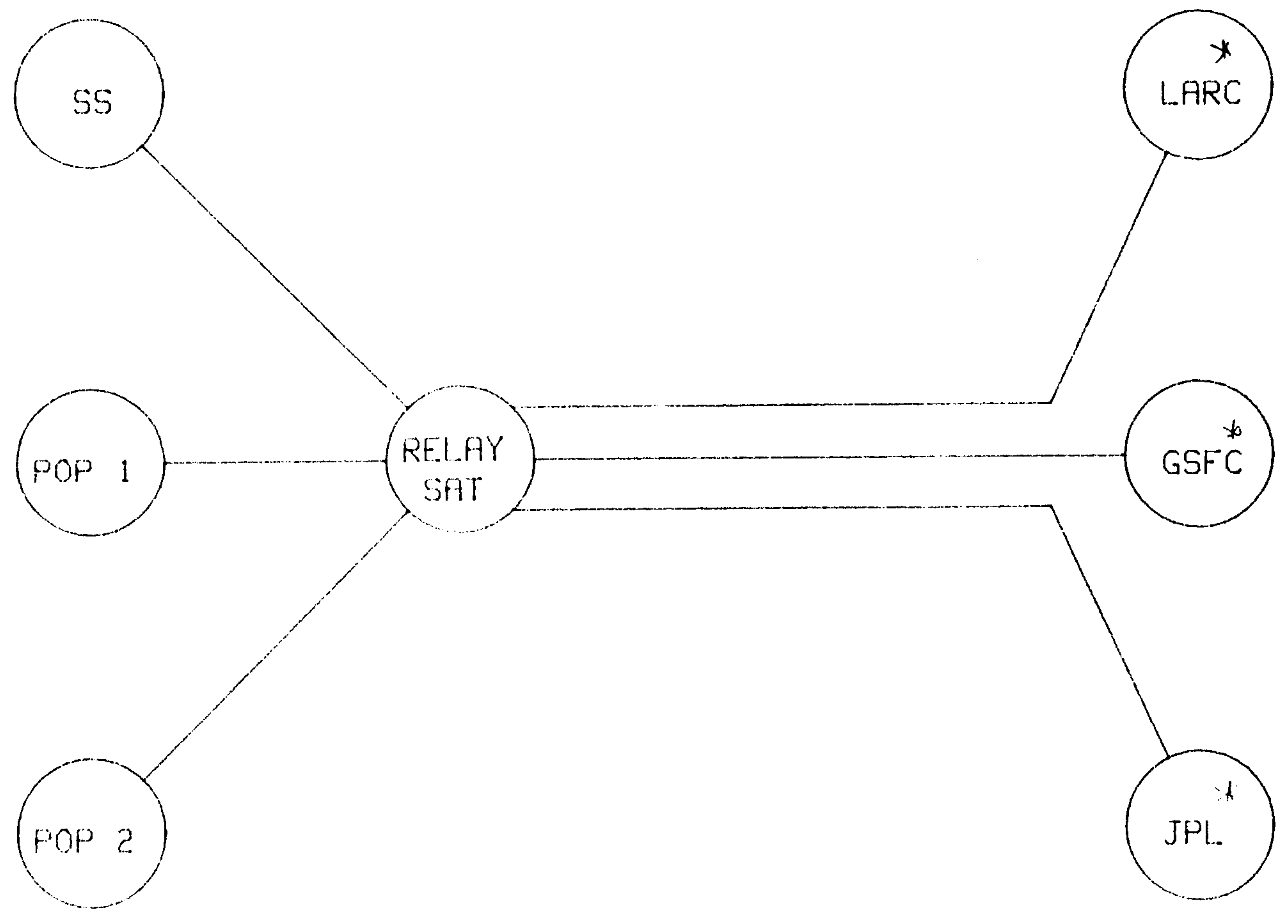
* DATA SET RECONSTRUCTION

Figure 2.5-2



* DATA SET RECONSTRUCTION

Figure 2.5-3



* DATA SET RECONSTRUCTION

Figure 2.5-4

	Option 1	Option 2	Option 3
Processing	All at White Sands	All at GSFC	Distributed at RDCS
Communications	Data Sets WS-RDCS	All WS-GSFC Data Sets GSFC-RDCS	Streams WS-RDCS

Figure 2.5-5. Processing and Communications Implications

Option 3 provides for the transmission of packets from White Sands to Level Zero Processing Facilities (LZPFs) and the reconstruction of data sets at the LZPF. The disadvantage of this approach is that the hardware, spares, and maintenance are distributed. There is also an increased configuration management burden. The advantage is that communications and buffering costs are minimized.

Option 4 presents physical links which have not yet been discussed; Space to LZPF. The disadvantage of studying this option is that there is a large degree of risk, as well as cost uncertainty. Also, the key cost issues are clearly SSIS issues. This option is presented in order to mention that there is a finite probability that data set reconstruction will necessarily be at the LZPF's in the future.

The first three topology options have been simulated and costed. Section 2.6 presents the simulation model and assumptions. Section 2.7 presents the assumptions used to derive system cost. Section 2.8 presents the preliminary results.

2.6 Simulation Description

Figures 2.6-1 through 2.6-3 illustrate the three models which were used to analyze the Space Station Network. These correspond to the three options discussed in Section 2.5. Many key assumptions were made in developing the simulation. These are not necessarily design decisions, they are assumptions required in order to make a working model. It is important to understand what these decisions are in order to evaluate their potential impact on the simulation results and any trade study conclusions based on these results.

2.6.1 Data Set Reconstruction

Traffic is entered into the system as data sets. These sets are broken into packets at the symbol labelled "deconstruct." These packets flow through the network until they reach the symbol labelled "reconstruct," then the data set flows through the rest of the system.

2.6.2 On Board Storage

Due to the high rates which are being buffered, it is assumed that there will be optical disks on board. This means that the on board buffer will be managed on a priority FIFO basis (tapes would be LIFO). As a result, payloads with low delay requirements are given priority over payloads with less stringent requirements.

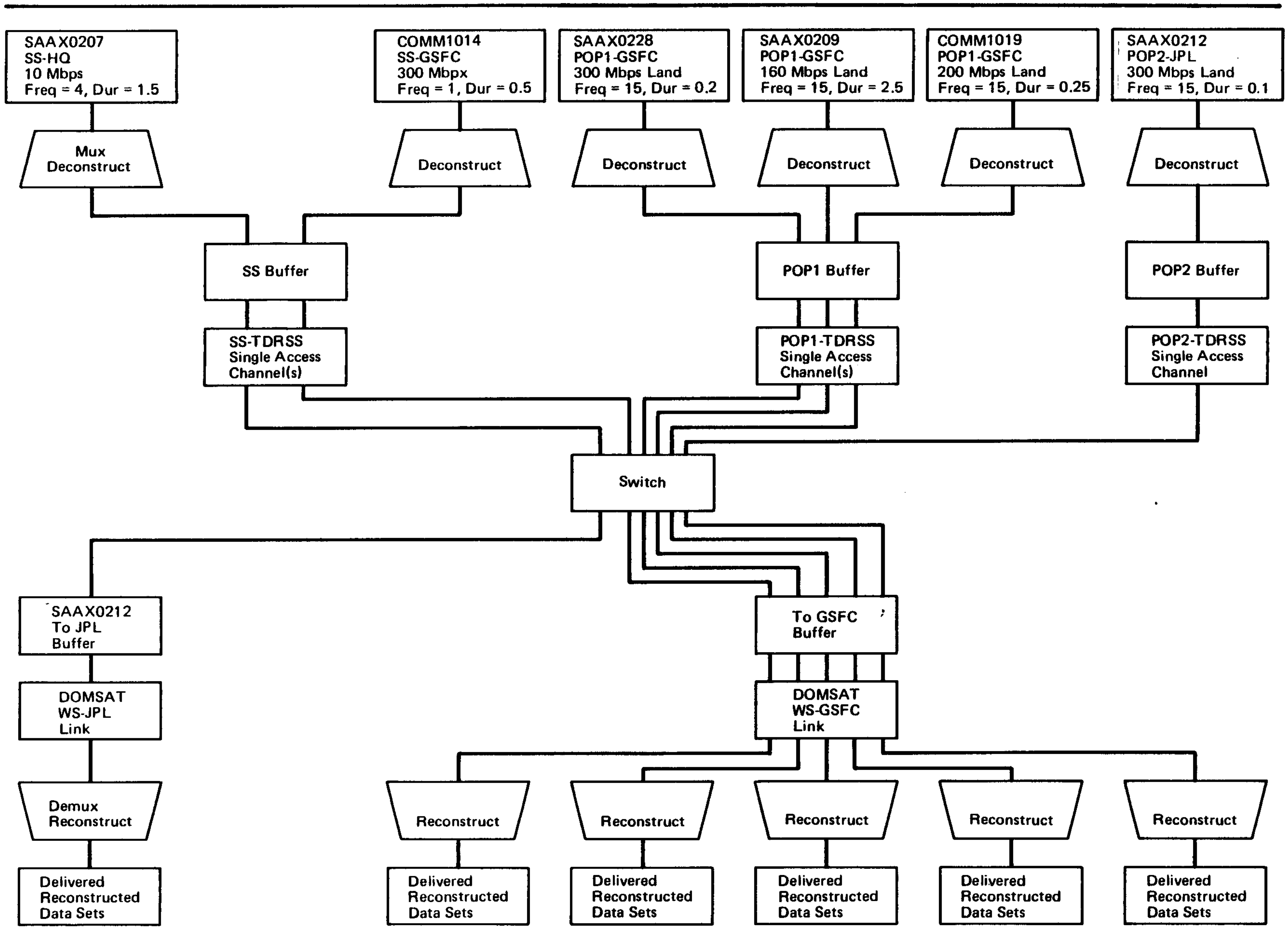


Figure 2.6-1. Network Model for Option No. 1

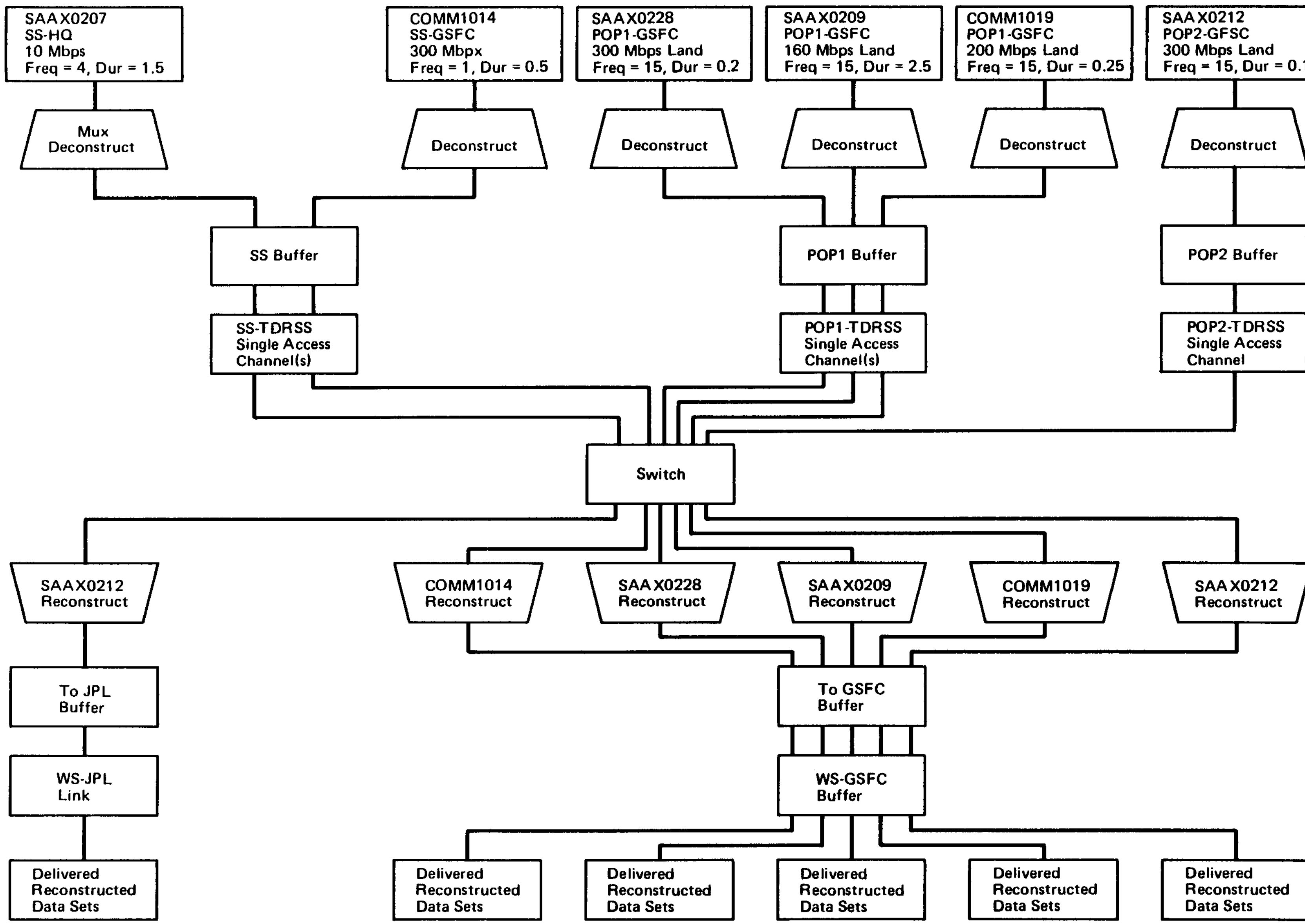


Figure 2.6-2. Network Model for Option No. 2

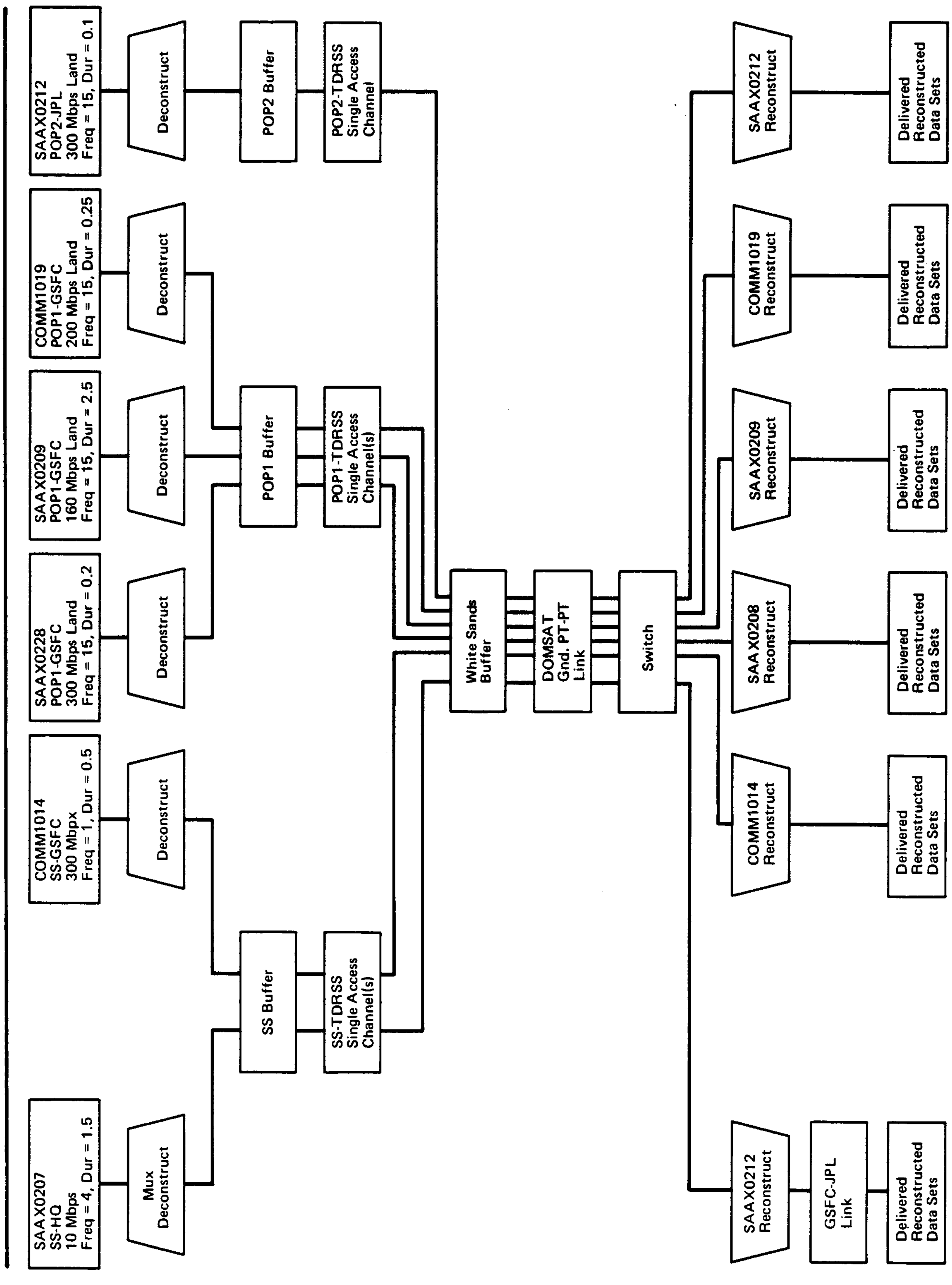


Figure 2.6-3. Network Model for Option No. 3

2.6.3 Ground Links

The bandwidths of the ground links is not varied in this study. For each link, a high bandwidth is chosen which will result in small queues. The bandwidths chosen are presented with the results.

2.6.4 Schedule Considerations

The good news for the SSDS is that payloads may be scheduled. The bad news is that many of the high rate payloads perform land observation. Figure 2.6-4 shows the data rates and triggers that were used by the simulation program.

Mission	From	To	Rate (Mbps)	Trigger
Comm1014	SS	GSFC	300	Land, P = 0.05
Saax0207	SS	GSFC	10	Poisson
Comm1019	POP 1	GSFC	200	Sunlit Land
Saax0209	POP 1	GSFC	160	Sunlit Land
Saax0228	POP 1	GSFC	30	Land, P = 0.46
Saax0212	POP 2	JPL	300	Land, P = 0.23

Figure 2.6-4. Simulation Traffic

2.6.5 TDRSS Single Access Channel Model

TDRSS Single Access Channels are modelled as a resource. For this purpose, it is assumed that the Space Station has two, POP1 and POP2, and POP2 has 1. The method of modelling one, two, or three channels is by having a TDRSS resource grabber (a.g.a. zone of non-contact (ZONC)) seize these resources with a high priority. Thus, to model a single access channel, the simulation is run with 5-n ZONCs. The ZONCs are scheduled so that for each spacecraft, the ZONC is at least as long as the maximum possible zone of exclusion.

2.7 Cost Assumptions

Each system configuration is assigned an associated cost. This is the combined cost for processing, buffering, and communications. Costs are measured on a normalized annual cost basis.

2.7.1 Processing Cost

According to a report by CSC (Advanced telemetry processing system feasibility study), the required systems will be available at a cost of 10.8 million dollars with a recurring cost of 465 thousand dollars. If the development cost is spread over two years with a zero percent interest rate, the normalized annual cost is $1.545 million-per-year per system. For topology options one and two, there will be one such system per single access channel. For option three, these systems, or smaller versions, will be judiciously distributed to the RDC's.

2.7.2 Buffer Costs

The buffer costs are described in detail in the Mass Storage trade study. The following costs are used here:

On board buffer	$10 per megabit
Ground buffer	$.20 per megabit

2.7.3 Communications Cost

Communications costs are extremely difficult to predict. Fiber Optic Systems appear to be the wave of the future, but costs are not quoted on a service basis. Because the communications service is outside of the scope of the SSDS, a very simple method has been derived to assign communications cost.

Based on technology trends (see Wide Area Network options) it is expected that communications costs will be around ten dollars per megabit per mile per year. Although satellite costs are mileage independent, this approach should result in a meaningful measure of cost.

Figure 2.7-1 shows the distances between the NASA centers. An example of the cost calculation is provided. The distance between GSFC and WS is 1,728 miles. Thus, the cost of 300 Mbps service is 10 *300* 1728 = $5,104 per year.

	GSFC	MSFC	JSC	JPL	LRC	LeRC
GSFC	0	711	1222	2289	139	305
WS	1728	1120	717	670	1751	1513

Figure 2.7-1. Miles Between NASA Sites

2.8 Preliminary Results

Computer simulations were run for each of the topology options defined in 2.5 for one, two and three TDRSS single access channels. Appendix F of the SSDS task 4 report provides details of the simulation runs. Appendix A of this study provides simulation outputs and cost calculations. Figure 3.1-1 provides a summary of the cost information.

Based on the results in Figure 3.1-1, Options 1 and 3 seems comparable. The communications costs make Option 2 prohibitive. Also, the cost difference between 2 or 3 TDRSS single access channels is small. If only one channel is used, on board buffering will cost an additional five million dollars per year.

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
TOTAL COST ($K/YR)

OPTION	TDRSS	COMMUNICATIONS	PROCESSING	BUFFER	TOTAL
1	1	1437	3090	10986	15513
1	2	1437	3090	5630	10157
1	3	1437	4635	4937	9464
2	2	4523	3090	10939	18552
2	2	8545	3090	5545	17180
2	3	12577	4635	4847	22059
3	1	1437	4635	10840	16912
3	2	1437	4635	5430	11502
3	3	1437	6180	4730	12347

Figure 3.1-1

3.0 Detailed Analysis

The results of the preliminary analysis of this trade study arrived at two basic conclusions. The first is that there should be two TDRSS single access channels. The second is that level 0 processing should be either centralized at White Sands or distributed to level zero processing centers (LZPFs) which would be colocated with RDCs. The next step of this trade study is to consider these options in greater detail. In addition to these two, a new option was considered which is a hybrid of the centralized and distributed options. For this "hybrid" option, the proceesing of the high rate payload data is distributed to the points of higher processing (RDCs) and the processing of the low rate data is centralized at Goddard. The detailed analysis of these three new options entails modelling each option in terms of cost elements and performing an economic analysis of the fixed and recurring costs. The sensitivities of these costs with respect to technology advances and requirements will then be analyzed. Section 3.1 provides a detailed analysis of the Langley data base mission traffic for the growth scenario

(1997). This information is used to size the cost elements. Section 3.2 describes the models of each of the three options. Section 3.3 describes the methodology which was used to assign costs to each of the model elements and provides a cost summary. In assigning these costs, it was very important to know whether or not the data is being rate smoothed. When rate smoothing is applied, data that does not have a strict (0 hour) delay requirement may be buffered in order to reduce both bandwidth and processing requirements. On the other hand, smoothing precludes quick-look (within seconds) analysis. This study analyzed the system costs both with and without rate smoothing. Section 3.4 describes the sensitivities of these costs to changes in mass storage and communications cost assumptions. Section 4 discusses the non-cost issues which were used to pick the Space Station ground network topology, and presents this selection.

3.1 Detailed Traffic Analysis

Figure 3.1-1a presents a data base report which was used to size the cost elements for the three options. These reports have two added columns which were used in sizing link bandwidths and smoothing requirements. The column labeled "required bandwidth" specifies the bandwidth requirement for the given payload as derived from the peak rate, average rate, and delay requirement. If the delay requirement is zero, then the required bandwidth is equal to the peak bandwidth. If the delay requirement is not zero, then it is assumed that the data can be smoothed, and therefore the required bandwidth is equal to the average bandwidth. The other column which was used to size the system was "Observation size". This is used to determine the size of the smoothing buffer. This is calculated by multiplying the peak rate by the duration. Figures 3.1-2 through 3.1-4 provide a point to point summary of the peak and average data rates. Figure 3.1- 2 provides this data for all 1997 missions. Figures 3.1-3 and 3.1-4 provide this data for high (10Mbps) and low rate payloads respectively.

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SPACE STATION TRAFFIC REPORT FOR YEAR 1997

FROM	MISSION #	1997 OPER DAYS	RATE (Mbps)	FREQ/DAY	DUR (hrs)	DELAY (hrs)	AVG BAND-WIDTH (Mbps)	REQ BAND-WIDTH (Mbps)	OBSER-VATION SIZE (Gbytes)
* TO GSFC									
COP	SAAX0004	5	1.00000	1.00	24.00	24.00	1.00000	1.00000	10.80000
PP1	COMM1019	365	200.00000	15.00	0.50	24.00	62.50000	62.50000	45.00000
PP1	SAAX0208	365	3.00000	7.00	0.50	3.00	0.43750	0.43750	0.67500
PP1	SAAX0209	365	160.00000	15.00	0.25	3.00	25.00000	25.00000	18.00000
PP1	SAAX0210	365	0.05000	1.00	24.00	3.00	0.05000	0.05000	0.54000
PP1	SAAX0216	365	0.00024	1.00	24.00	3.00	0.00024	0.00024	0.00259
PP1	SAAX0228	365	30.00000	15.00	0.20	3.00	3.75000	3.75000	2.70000
PP1	SAAX0230	365	0.00500	15.00	0.75	3.00	0.00234	0.00234	0.00168
PP1	SAAX0238	365	0.03000	1.00	24.00	3.00	0.03000	0.03000	0.32400
PP2	SAAX0211	365	0.04000	15.00	0.75	3.00	0.01875	0.01875	0.01350
PP2	SAAX0213	365	0.01000	1.00	24.00	3.00	0.01000	0.01000	0.10800
PP2	SAAX0214	365	0.01000	1.00	24.00	3.00	0.01000	0.01000	0.10800
PP2	SAAX0219	365	0.00250	0.10	24.00	0.00	0.00025	0.00250	0.02700
PP2	SAAX0220	365	0.02000	1.00	24.00	3.00	0.02000	0.02000	0.21600
PP2	SAAX0225	365	2.00000	4.00	4.00	0.00	1.33000	2.00000	3.60000
PP2	SAAX0229	365	0.01000	15.00	0.75	3.00	0.00468	0.00468	0.00337
PP2	SAAX0231	365	2.00000	1.00	24.00	3.00	2.00000	2.00000	21.60000
PP2	SAAX0232	365	0.01000	1.00	24.00	3.00	0.01000	0.01000	0.10800
PP2	SAAX0234	365	0.01000	1.00	24.00	3.00	0.01000	0.01000	0.10800
PP2	SAAX0235	365	0.02000	1.00	24.00	3.00	0.02000	0.02000	0.21600
PP3	SAAX0233	365	0.00300	1.00	24.00	3.00	0.00300	0.00300	0.03240
PP3	SAAX0236	365	0.03000	15.00	0.75	3.00	0.01406	0.01406	0.01012
PP3	SAAX0237	365	0.01000	15.00	0.75	3.00	0.00468	0.00468	0.00337
SS	COMM1014	90	300.00000	1.00	0.20	24.00	2.50000	2.50000	27.00000
SS	COMM1202	365	0.00500	1.00	24.00	24.00	0.00500	0.00500	0.05400
SS	SAXX0011	365	50.00000	15.00	1.00	0.00	31.25000	50.00000	22.50000
SS	TDMX2261	365	0.01000	1.00	4.00	0.00	0.00167	0.01000	0.01800
** SUBTOTAL **									
			748.27574	161.10	350.40	153.00	129.98217	149.41275	153.76903
* TO JPL									
PP2	SAAX0212	365	300.00000	15.00	0.10	6.00	18.75000	18.75000	13.50000
** SUBTOTAL **									
			300.00000	15.00	0.10	6.00	18.75000	18.75000	13.50000
* TO JSC									
SS	COMM1206	365	0.00500	4.00	1.00	24.00	0.00500	0.00500	0.00225
** SUBTOTAL **									
			0.00500	4.00	1.00	24.00	0.00500	0.00500	0.00225

Figure 3.1-1a. 1997 Data Base Listing

SPACE STATION TRAFFIC REPORT FOR YEAR 1997

FROM	MISSION #	1997 OPER DAYS	RATE (Mbps)	FREQ/DAY	DUR (hrs)	DELAY (hrs)	AVG BAND-WIDTH (Mbps)	REQ BAND-WIDTH (Mbps)	OBSER-VATION SIZE (Gbytes)
* TO LANG									
SS	SAAX0227	365	50.00000	1.00	8.00	0.00	16.67000	50.00000	180.00000
** SUBTOTAL **									
			50.00000	1.00	8.00	0.00	16.67000	50.00000	180.00000
* TO MSFC									
PP2	SAAX0005	365	0.10000	1.00	24.00	24.00	0.10000	0.10000	1.08000
SS	COMM1201	365	0.05000	4.00	1.00	24.00	0.00833	0.00833	0.02250
SS	COMM1203	180	0.00200	1.00	24.00	24.00	0.00200	0.00200	0.02160
SS	COMM1204	365	0.05000	4.00	1.00	24.00	0.00833	0.00833	0.02250
SS	SAAX0401	365	0.05000	1.00	24.00	3.00	0.05000	0.05000	0.54000
SS	SAAX0404	365	0.05000	1.00	24.00	3.00	0.05000	0.05000	0.54000
SS	TDMX2011	365	0.00200	1.00	0.25	1.00	0.00002	0.00002	0.00022
SS	COMM1208	365	0.00200	1.00	24.00	24.00	0.00200	0.00200	0.02160
** SUBTOTAL **									
			0.30600	14.00	122.25	127.00	0.22068	0.22068	2.24842
** TOTAL **									
			1098.58674	195.10	481.75	310.00	165.62785	218.38843	349.51970

Figure 3.1-1a (Cont'd). 1997 Data Base Listing (Continued)

AVERAGE (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	33757	120	1			16667	50545
COP	1000						1000
POP 1	91771	100					91871
POP 2	3439			18750			22189
POP 3	23						23
TOTAL	129990	220	1	18750		16667	165628

PEAK (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	350015	206	5			50000	40026
COP	1000						1000
POP 1	393085	100					393185
POP 2	4132			300000			304132
POP 3	43						43
TOTAL	748275	306	5	300000		50000	1098586

Figure 3.1-2. 1997 Missions

AVERAGE (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	33750					16667	50417
COP							
POP 1	91250						91250
POP 2				18750			18750
POP 3							
TOTAL	125000			18750		16667	160417

PEAK (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	350000					50000	400000
COP							
POP 1	390000						390000
POP 2				300000			300000
POP 3							
TOTAL	740000			300000		50000	1090000

Figure 3.1-3. 1997 High Rate Missions (> 10 MBPS)

AVERAGE (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	7	120	1				128
COP	1000						1000
POP 1	521	100					621
POP 2	3439						3439
POP 3	23						23
TOTAL	4990	220	1				5211

PEAK (KBPS)

	GSFC	MSFC	JSC	JPL	LeRC	LaRC	TOTAL
SS	15	206	5				226
COP	1000						1000
POP 1	3085	100					3185
POP 2	4132						4132
POP 3	43						43
TOTAL	8275	306	5				8586

Figure 3.1-4. 1997 Low Rate Missions (< 10 MBPS)

3.2 Options Description

Sections 3.2.1 through 3.2.3 describe the three options which were considered in detail.

3.2.1. Centralized Option

Figure 3.2–1 illustrates the centralized processing option. The values in the boxes are used for sizing and costing the system. These values are derived from the Langley data base, as described in Section 3.1. At the front end of the ground system is a bulk recorder. This may be used to record all of the data which arrives at the ground terminal. The data is then level 0 processed at White Sands. This process naturally smoothes out the data, and it is then transmitted to the RDCs at the required rate. It should be noted that payloads with a zero delay requirement may get their data with zero delay, but it will not be level 0 processed. Production data sets may be sent to these users after they have been processed, and as such with some delay.

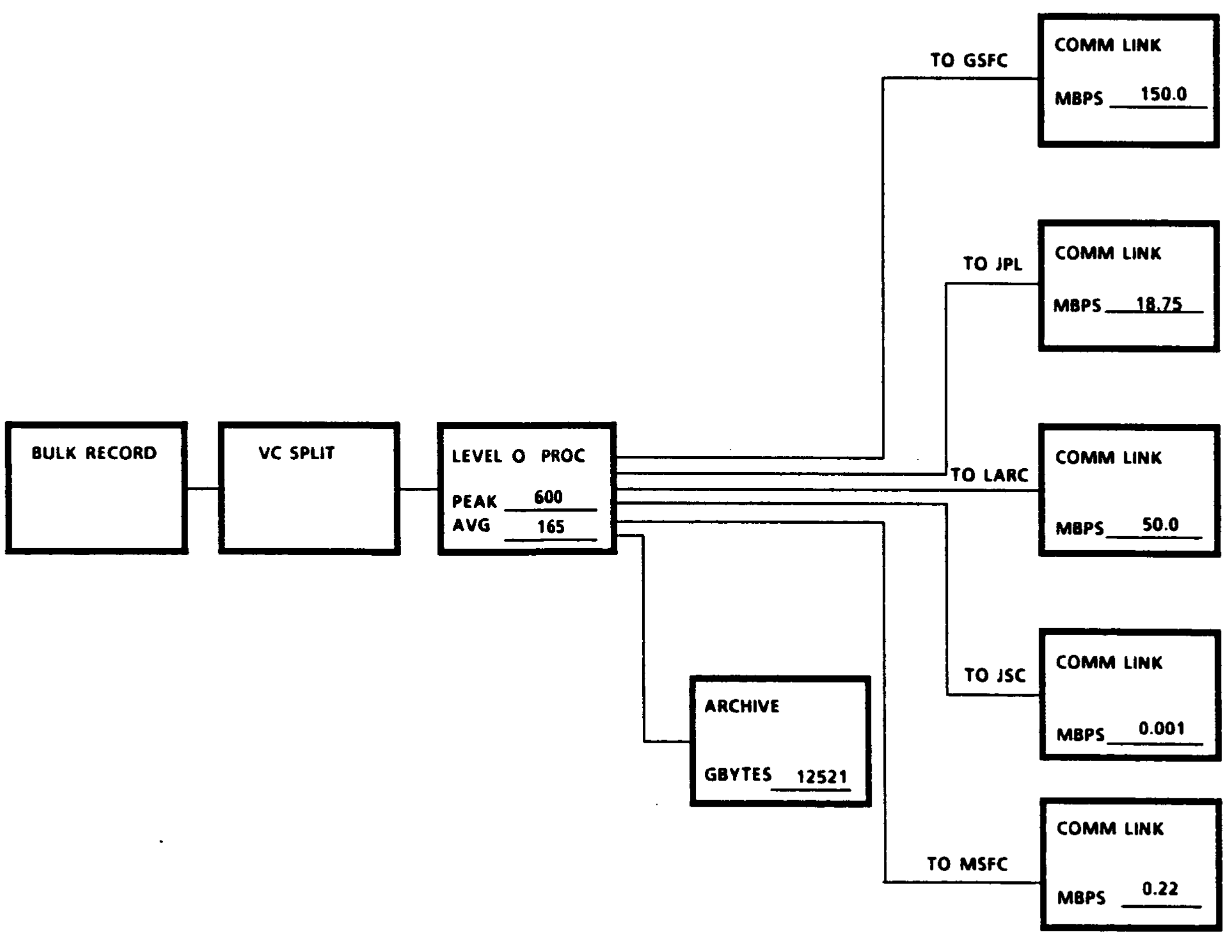

Figure 3.2-1. Option 1 — Centralized

3.2.2. Hybrid Option

Figures 3.2–2a and 3.2–2b illustrate the hybrid system with and without smoothing. The differences between these figures is the peak communications bandwidth and the peak level 0 processing requirement. In the case where smoothing is assumed, the peaks are assumed to be equal to the averages for data with non-zero delay requirements. This will, in turn, be reflected in the communications costs and the level 0 hardware costs.

For the hybrid option, a virtual channel splitter is used to route high rate data streams directly to where the RDCs for those streams are located. The level 0 processing for these payloads is then performed at collocated level 0 processing facilities (LZPFs). The channel which contains the multiplexed low rate data is routed to Goddard where it is processed and then transmitted to the appropriate RDC. Because some of this data has a zero delay requirement, and there is no mechanism at White Sands to sort down to the packet level, the entire stream must be sent with no delay. For purposes of this analysis, this means that the link bandwidth for this stream must be 8.6 Megabits per second.

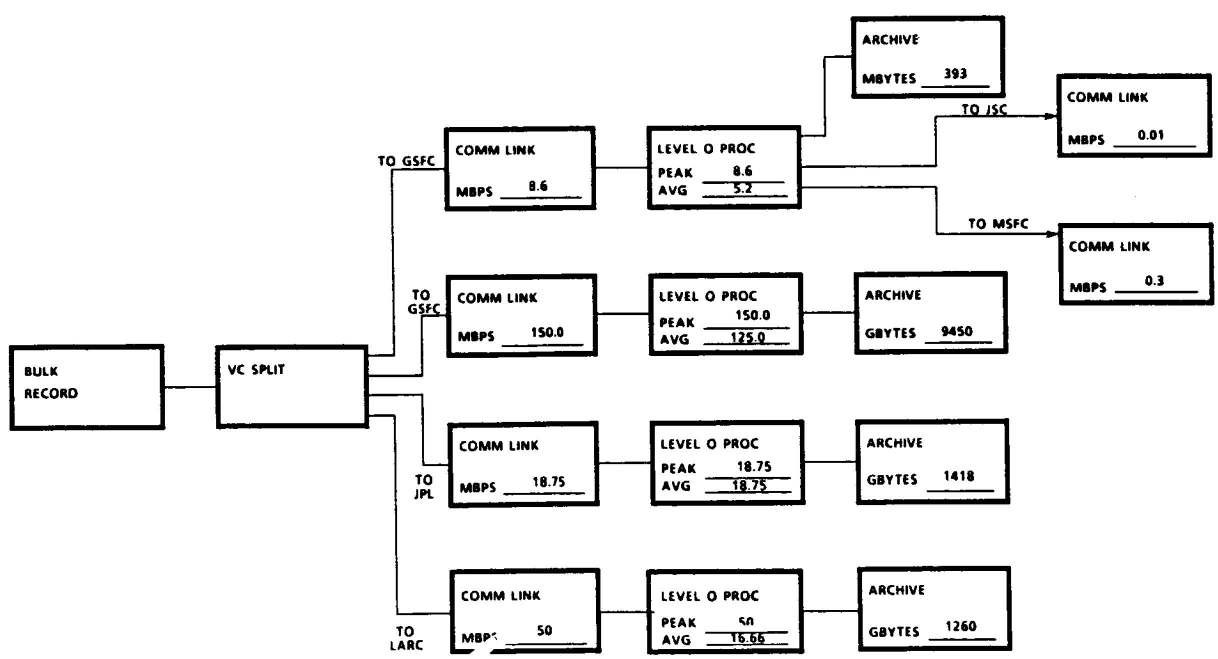

Figure 3.2-2a. Option 2 – Hybrid (With Smoothing)

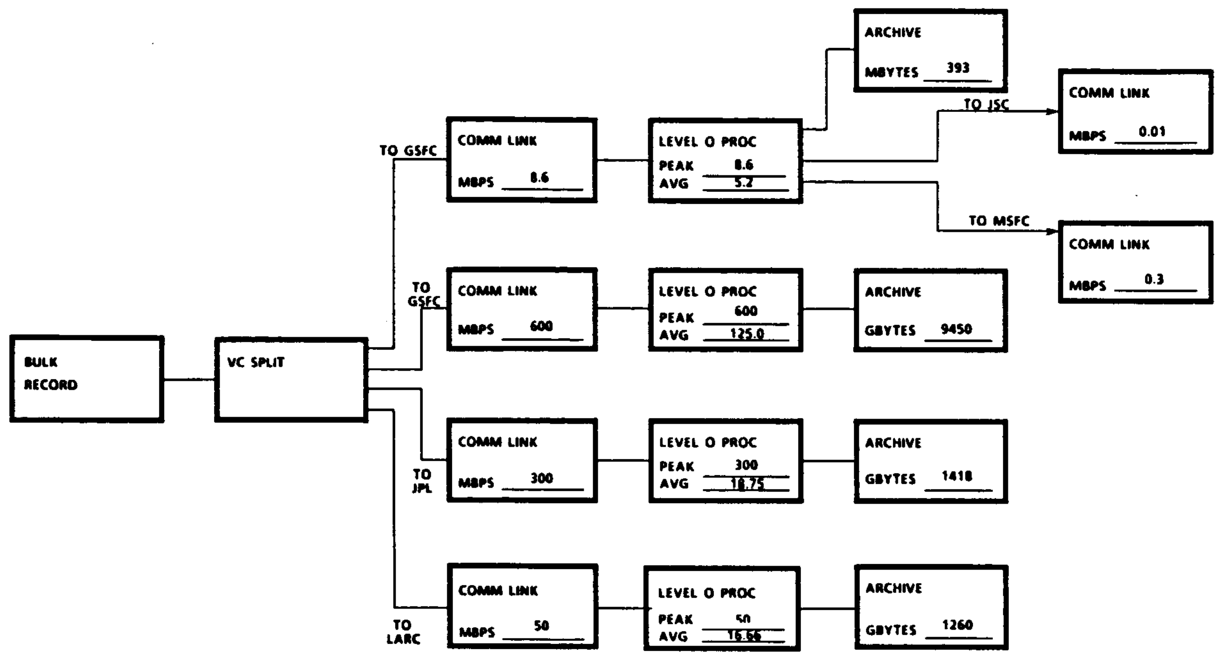

Figure 3.2-2b. Option 2 – Hybrid (Without Smoothing)

3.2.3. Distributed Option

Figures 3.2–3a and 3.2–3b illustrate the distributed system with and without smoothing. For the distributed option, a virtual channel splitter is used to route high rate data streams directly to where the RDCs for those streams are located. The level 0 processing for these payloads is then performed at colocated level 0 processing facilities (LZPFs). The channel which contains the multiplexed low rate data is processed down to packets at White Sands and the packets are then sent to the low rate LZPFs for processing.

3.3 Cost Assumptions

Figure 3.3–1 illustrates the cost breakdown structure that was used to analyze the cost differences between the three options. It should be noted that this structure includes cost elements which are not within the SSDS. The purpose of this exercise is to obtain a consistent measure which may be used to understand the overall cost implications of the various options. Any

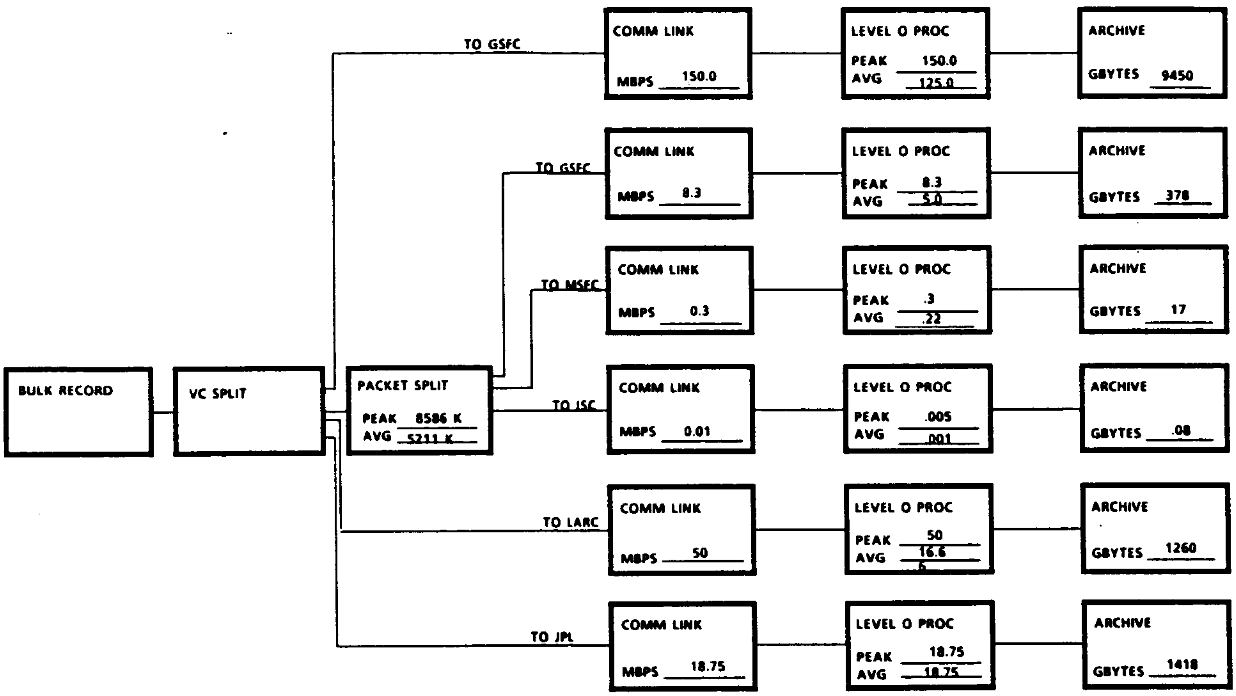

Figure 3.2-3a. Option 3 – Distributed (With Smoothing)

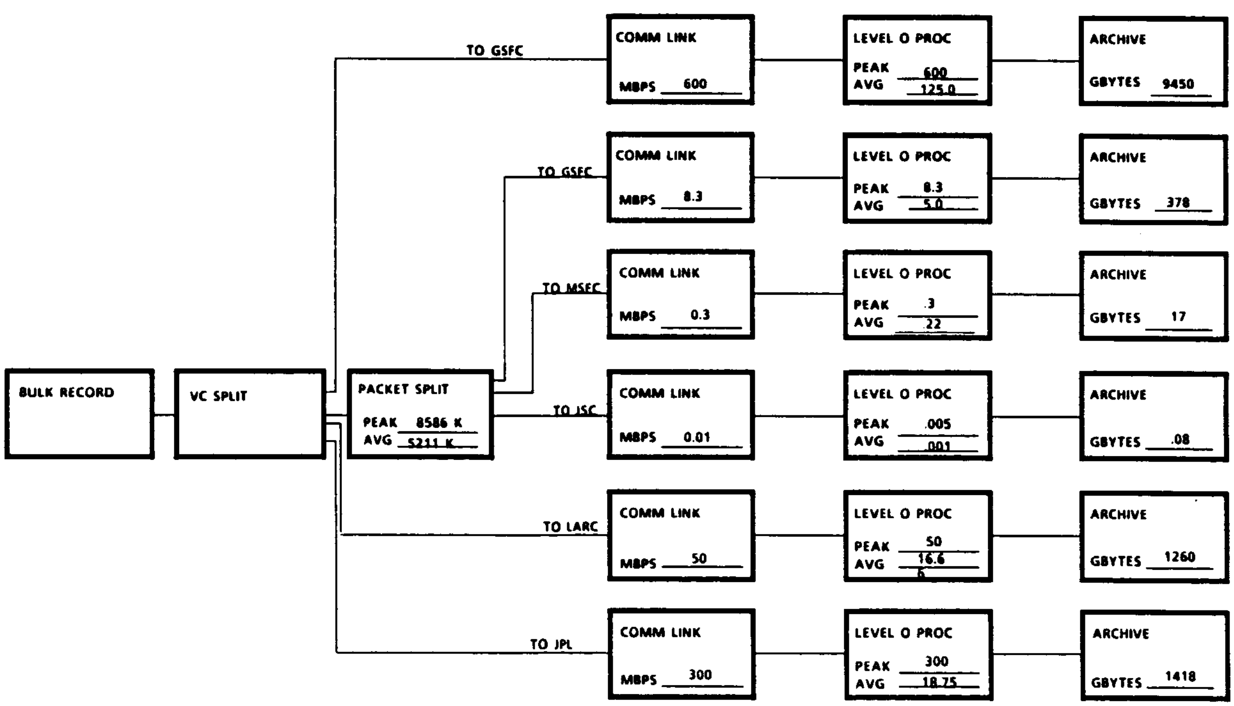

Figure 3.2-3b. Option 3 – Distributed (Without Smoothing)

SSDS Payload Data Processing Cost Elements

I. Bulk Storage (Fixed)

II. Virtual Channel Splitter (Fixed)

III. Level O Hardware

- A.) Processors, Special Purpose Hardware (Fixed)
- B.) Maintenance

IV. Level O Software

- A.) SW Development and Test (Fixed)
- B.) SW Maintenance

V. Level O Working Storage (Fixed)

VI. Archival Storage

- A.) System and Drives (Fixed)
- B.) Media (Recurring)

VII. Operations (Recurring)

VIII. Communications Bandwidth (Recurring)

IX. Smoothing Cost

- A.) Device (Fixed)
- B.) Media (Recurring)

Figure 3.3-1. Cost Breakdown Structure

statement of source of information in no way implies any intent to use the product specified. It simply specifies the method which was used to obtain cost estimates. Figures 3.3-2 through 3.3-7 illustrate the costs which were derived from the cost analysis for each of the three options with and without smoothing. Figure 3.3-8 provides a summary of this information in the form of total fixed (development) and recurring costs for each case. Sections 3.3.1 through 3.3.9 discuss the cost models which were used to arrive at these numbers. Each of these sections is divided into subsections which describe the rationale used in developing the cost model derived for that particular element and the application of the model to the systems being analyzed.

3.3.1 Bulk Recorder (fixed)

3.3.1.1 Cost Model Ampex is currently developing tape recorder which is capable of capturing 350 Mbps. It is projected that this recorder will cost around $250 thousand.

Cost Analysis of Option 1
Centralized at White Sands
(assuming smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	31.2	
	B) Maintenance		3.7
IV.	Level 0 Software		
	A) Develop & Test	27.5	
	B) SW Maintenance		5.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		1.2
VIII.	Comm Bandwidth		3.6
IX.	Smoothing Cost		
	A) Device		
	B) Media		
		120.0	15.3

Figure 3.3-2

Cost Analysis of Option 2
Hybrid System
(assuming smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	38.7	
	B) Maintenance		4.6
IV.	Level 0 Software		
	A) Develop & Test	32.5	
	B) SW Maintenance		6.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		3.6
VIII.	Comm. Bandwidth		3.6
IX.	Smoothing Cost		
	A) Device	0.5	
	B) Media		0.8
		133.0	20.4

Figure 3.3-3

Cost Analysis of Option 3
Distributed System
(assuming smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	40.3	
	B) Maintenance		4.8
IV.	Level 0 Software		
	A) Develop & Test	37.5	
	B) SW Maintenance		7.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		6.0
VIII.	Comm. Bandwidth		3.6
IX.	Smoothing Cost		
	A) Device	0.5	
	B) Media		0.8
		139.6	24.0

Figure 3.3-4

Cost Analysis of Option 1
Centralized at White Sands
(assuming no smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	31.2	
	B) Maintenance		3.7
IV.	Level 0 Software		
	A) Develop & Test	27.5	
	B) SW Maintenance		5.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		1.2
VIII.	Comm. Bandwidth		3.6
IX.	Smoothing Cost		
	A) Device		
	B) Media		
		120.0	15.3

Figure 3.3-5

Cost Analysis of Option 2
Hybrid System
(assuming no smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	53.1	
	B) Maintenance		6.4
IV.	Level 0 Software		
	A) Develop & Test	32.5	
	B) SW Maintenance		6.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		3.6
VIII.	Comm. Bandwidth		13.3
IX.	Smoothing Cost		
	A) Device		
	B) Media		
		146.9	31.1

Figure 3.3-6

Cost Analysis of Option 3
Distributed System
(assuming no smoothing)

		FIXED ($M)	RECURRING ($M)
I.	Bulk Recorder	1.0	
II.	Channel Splitter	3.0	
III.	Level 0 Hardware		
	A) Processors, special purpose hardware	55.6	
	B) Maintenance		6.7
IV.	Level 0 Software		
	A) Develop & Test	37.5	
	B) SW Maintenance		7.5
V.	Level 0 Working Storage	7.4	
VI.	Archival Storage		
	A) System and Drives	49.9	
	B) Media		1.3
VII.	Operations		6.0
VIII.	Comm. Bandwidth		13.3
IX.	Smoothing Cost		
	A) Device		
	B) Media		
		153.9	34.8

Figure 3.3-7

WITH SMOOTHING

OPTION	FIXED ($M)	RECURRING ($M)
CENTRALIZED	120.0	15.3
HYBRID	133.0	20.4
DISTRIBUTED	139.6	24.0

WITHOUT SMOOTHING

OPTION	FIXED ($M)	RECURRING ($M)
CENTRALIZED	120.0	15.3
HYBRID	146.9	31.1
DISTRIBUTED	153.9	34.8

Figure 3.3-8. Results, Cost for Defined System Elements

3.3.1.2 Actual Cost

For each option, the cost for the bulk recorders is assumed to be one million dollars.

3.3.2 Virtual Channel Splitter (fixed)

3.3.2.1 Cost Model

The functions of the virtual channel splitter are similar in nature to those of the Ford TAC. The rates which must be supported, however, are about two orders of magnitude higher. It is assumed the development and production costs will be about one order of magnitude higher.

3.3.2.2 Actual Cost

For each option, the cost for virtual channel splitter is three million dollars.

3.3.3 Level 0 Hardware

Sections 3.3.3.1 and 3.3.3.2 provide the cost model and actual costs for the three options with and without smoothing. Within this analysis an effort has been made to determine when redundant systems will be necessary to support reliability requirements. Redundancy is assumed more often in the case of no smoothing, because in this case the LZPF is the first place in the system (other than the bulk record) where the data is stored. Sections 3.3.3.3 and 3.3.3.4 provide the cost model and actual recurring costs for hardware maintenance.

3.3.3.1 Hardware Cost Model

The functions of the high rate level 0 hardware are similar in nature to those of the advanced telemetry processing system(ATPS). The actual ATPS studies assumed that the downlink would contain 5% TDM data and 95% packet data. The SSDS assumptions call for 100% packet data. The architecture of the ATPS allows for modular addition of high performance processors (HPPs) to accommodate various bit rates. It is estimated by CDC that each HPP is capable of handling 80Mbps of packet data. The cost provided for a basic system which includes two HPPs is 5.4 million dollars. Each additional HPP can be configured for 1.2 million dollars.

In order to cost low rate level 0 processing, the PACOR system was used as a baseline. This system is able to process a peak rate of 1.5 Mbps and the SEL hardware costs about $400,000. For the actual PACOR application, level three protocols are handled in the software. It is estimated that if this function could be offloaded onto a board, the rate could be increased to 4 Mbps. Many processor manufacturers offer families of computers which offer a range of options in terms of capabilities in this range. The cost for low rate level 0 processing is thus assumed to be linearly related to the rate ($0.1 per bps) subject to a floor of $400,000.

3.3.3.2 Actual Hardware cost

Option one (centralized) with smoothing:

At White Sands, one system per SA channel is required with the capability to handle 300 MBPS. Such a system would require four HPPs. For purposes of reliability, redundant systems have been assumed. Thus, the total cost for this option is $31.2 million.

Option one (centralized) without smoothing:

Same as option one with smoothing

Option two (hybrid) with smoothing:

At Goddard, one high rate system is required with the capability to handle 150 MBPS. For purposes of reliability, redundant systems have been assumed.

At Langley, one high rate system is required with the capability to handle 50 MBPS.

At JPL, one high rate system is required with the capability to handle 18.75 MBPS.

At Goddard, one low rate system is required with the capability to handle 8.6 MBPS.

The total cost for this option is $38.7 million.

Option two (hybrid) without smoothing:

At Goddard, two high rate systems are required with the capability to handle 300 MBPS. For purposes of reliability, redundant systems have been assumed.

At Langley, one high rate system is required with the capability to handle 50 MBPS.

At JPL, one high rate system is required with the capability to handle 300 MBPS. For purposes of reliability, redundant systems have been assumed.

At Goddard, one low rate system is required with the capability to handle 8.6 MBPS.

The total cost for this option is $53.1 million.

Option three (distributed) with smoothing:

At Goddard, one high rate system is required with the capability to handle 150 MBPS. For purposes of reliability, redundant systems have been assumed.

At Langley, one high rate system is required with the capability to handle 50 MBPS.

At JPL, one high rate system is required with the capability to handle 18.75 MBPS.

At MSFC, one low rate system

At JSC, one low rate system

At Goddard, one low rate system is required with the capability to handle 8.3 MBPS.

The total cost for this option is $40.3 million.

Option three (distributed) without smoothing:

At Goddard, two high rate system is required with the capability to handle 300 MBPS. For purposes of reliability, redundant systems have been assumed.

At Langley, one high rate system is required with the capability to handle 50 MBPS.

At JPL, one high rate system is required with the capability to handle 300 MBPS. For purposes of reliability, redundant systems have been assumed.

At Goddard, one low rate system is required with the capability to handle 8.3 MBPS.

At MSFC, one low rate system

At JSC, one low rate system

The total cost for this option is $55.6 million.

3.3.3.3 Maintenance Cost Model

A long-standing rule of thumb is that hardware maintenance costs one percent per month of the hardware cost.

3.3.3.4 Actual Maintenance Cost

Option one with Smoothing:	$3.7 Million per year
Option one without Smoothing:	$3.7 Million per year
Option two with Smoothing:	$4.6 Million per year
Option two without Smoothing:	$6.4 Million per year
Option three with Smoothing:	$4.8 Million per year
Option three without Smoothing:	$6.7 Million per year

3.3.4 Level 0 Software

Sections 3.3.4.1 and 3.3.4.2 provide the software cost model and actual costs for the three options. Sections 3.4.3.3 and 3.4.3.4 provide the cost model and actual recurring costs for software maintenance.

3.3.4.1 Software Cost Model

The total system cost for software is assumed to grow proportionally with the number of locations over which the software is distributed. Due to the use of standard CCSDS packets, it is expected that a large quantity of software will be existing and reusable. Based on these two facts, the following formula has been derived to predict the cost of the level zero software:

level 0 software cost = $25M * (1 + 0.1 * (number of locations))

3.3.4.2 Software Actual Cost

Cost For option 1: $27.5M
Cost For option 2: $32.5M
Cost For option 3: $37.5M

3.3.4.3 Software Maintenance Cost Model

The following formula has been derived to predict the cost of the software maintenance cost:

Maintenance cost = Development cost * .2

3.3.4.4 Actual Software Maintenance Cost

Cost For option 1: $5.5M
Cost For option 2: $6.5M
Cost For option 3: $7.5M

3.3.5 Level 0 Working Storage (Fixed)

The cost of both working storage and archival (7 day) storage are very sensitive and very high. For this reason, a parametric cost model has been constructed for each of these. Given the parametric models, appropriate parameters which define the SSDS requirements are plugged in to derive the cost.

3.3.5.1 Level 0 Working Storage Cost Model

It is assumed that the working storage will be supported using fixed magnetic disks. The following is an analysis of the cost of magnetic disk based systems. The costs will be derived as a function of the data rate entering the system and the duration of time which the data must be stored.

Parameters:

h - Hours of storage required
r - average data rate (megabits per second)
A - "Archive size"(gigabytes)
c1 - cost per disk
g1 - gigabytes per disk

Calculations

$$A(\text{gigabytes}) = r\ (\text{megabits/sec}) * h\ (\text{hours}) * 60\ (\text{min/hour}) * 60\ (\text{sec/min}) * .125\ (\text{bytes/bit}) * .001\ (\text{giga/mega})$$
$$= r * h * 0.45$$

$$\text{System cost} = \text{number of disks} * \text{cost per disk}$$
$$= (A/g1)*c1$$

Cost

$$(0.45 * r * h * c1\ ) / g1$$

3.3.5.2 Actual Level 0 Working Storage Cost

Actual Cost Assumptions (Based on existing RA81 3-pack)

g1 = 1.2 gigabytes
c1 = $40,000

Actual Requirements

r = 165 Mbps

h = 3 hours

Therefore, for each option, the cost for level 0 working storage is $7.4 million.

3.3.6 Archival (7 day) Storage

It is assumed that the seven day storage requirement will be supported using erasable optical disks. As such, in addition to the fixed development cost there is a recurring cost associated with supplying the media. Sections 3.3.6.1 and 3.3.6.2 provide the cost model and actual costs for both the development and recurring media costs.

3.3.6.1 Archival Storage Cost Model

The following is an analysis of the cost of optical disk based systems. The costs are derived as a function of the data rate entering the system and the duration of time which the data must be stored.

For the analysis of optical systems, it is assumed that the media must be replaced. This analysis develops parametric cost models for fixed (3.3.6.1) and recurring (3.3.6.3) cost.

It is assumed that not all disks will be "on-line". "On-line" disks are mounted in drives. Automatic retrieval (ala jukebox) is assumed. A percentage of on line storage is assumed based on similar existing systems. The cost for on-line gigabytes includes high speed drive, support software, and retrieval system.

Parameters

h - Hours of storage required

r - average data rate (megabits per second)

A - "Archive size"(gigabytes)

p - proportion of on-line storage

c2 - cost per gigabyte on-line storage

c3 - media cost per disk

g2 - gigabytes per disk

W - Writes per Disk

Calculations

Fixed cost Calculation

On-line gigabytes = p * r * h * 0.45

fixed cost = on-line gigabytes * cost per on-line gigabyte

Recurring cost

Recurring cost = Cost to fill archive * number of times per yr media replaced

Cost to fill = disks required to fill * cost per disk
= (A/g2)*c2
= (0.45 * r * h * c3) / g2

Times media replaced = times archive filled / writes per disk

Times archive filled = hours per year / hours to fill
= (365 * 24) / h

Times media replaced = (365 * 24) / (h * W)

Cost

Fixed cost = c2 * p * r * h * 0.45 recurring cost
= (3942 * r) * (c3 / (W * g2))

3.3.6.2 Actual Archival Storage Cost

Actual Cost Assumptions

p = 0.2 (20 %)
c2 = $20,000 / megabyte
c3 = $400 / disk
g2 = 2 gigabytes
W = 100 writes per disk

Actual Requirements

r = 165 Mbps
h = 168 Hours

Therefore, for each option, the fixed cost for archival is $49.9 Million and the recurring cost is $1.3M per year.

3.3.7 Operations (recurring)

3.3.7.1 Operations Cost Model

It is determined that six full-time(24 hour) positions will be required to support the SSDS functions at each LZPF. This translates to twenty-four individuals. Assuming that each individual costs fifty thousand dollars per year, the formula for the recurring operations cost is :

Operations Cost = (# OF RDCS) * $1.2M

3.3.7.2 Actual Operations Cost

Cost For option 1 : $1.2M

Cost For option 2 : $3.6M

Cost For option 3 : $6.0M

3.3.8 Communications Bandwidth (recurring)

3.3.8.1 Communications Bandwidth Cost Model

It is important to note that this is not an SSDS function, and will not be reflected in the SSDS design. It is necessary to consider this element to understand cost differences between centralized vs distributed system. It is also important to understand the sensitivity of the system cost and system design to the cost of the communications.

In order to measure the communications cost, a variable must be selected which represents the state of the art of communications. It is assumed that the communications media will be optical fibers, and therefore the cost is measured in dollars per Mbps per mile per year. Based on projected fiber optics costs, the figure $10/Mbps/mile/yr is used.

3.3.8.2 Actual Communications Bandwidth Cost Model

Figures 3.3-9 and 3.3-10 derive the communications cost for each option with and without smoothing. The following is a summary of these costs.

Option one with Smoothing:	$3.6 Million per year
Option one without Smoothing:	$3.6 Million per year
Option two with Smoothing:	$3.6 Million per year
Option two without Smoothing:	$13.3 Millionper year
Option three with Smoothing:	$3.6 Million per year
Option three without Smoothing:	$13.3 Million per year

Communications Cost Analysis
(assuming smoothing)

Option 1 - Centralized at White Sands

Link	Mbps	Miles	Mbps*Miles
WS-GSFC	150.00	1728	259200
WS-JPL	18.75	670	12562
WS-LARC	50.00	1751	87550
WS-MSFC	0.22	1120	246
WS-JSC	0.00	717	0
TOTAL			359558

Option 2 - Hybrid

Link	Mbps	Miles	Mbps*Miles
WS-GSFC	150.22	1728	259580
WS-JPL	18.75	670	12562
WS-LARC	50.00	1751	87550
GS-MSFC	0.22	711	156
GS-JSC	0.00	1222	0
TOTAL			359848

Option 3 - Distributed

Link	Mbps	Miles	Mbps*Miles
WS-GSFC	150.00	1728	259200
WS-JPL	18.75	670	12562
WS-LARC	50.00	1751	87550
WS-MSFC	0.22	1120	246
WS-JSC	0.00	717	0
TOTAL			359558

Communications Cost

Option	Mbps*Miles	$/Mbps/Mile/Yr	$/Yr
1	359558	10	3,595,580
2	359848	10	3,598,480
3	359558	10	3,595,580

Figure 3.3-9

Communications Cost Analysis
(assuming no smoothing)

Option 1 – Centralized at White Sands

Link	Mbps (avg)	Miles	Mbps*Miles
WS–GSFC	150.00	1728	259200
WS–JPL	18.75	670	12562
WS–LARC	50.00	1751	87550
WS–MSFC	0.22	1120	246
WS–JSC	0.00	717	0
TOTAL			359558

Option 2 – Hybrid System

Link	Mbps (peak)	Miles	Mbps*Miles
WS–GSFC	600.00	1728	1036800
WS–JPL	300.00	670	201000
WS–LARC	50.00	1751	87550
GS–MSFC	0.31	711	220
GS–JSC	0.01	1222	12
TOTAL			1325582

Option 3 – Distributed

Link	Mbps (peak)	Miles	Mbps*Miles
WS–GSFC	600.00	1728	1036800
WS–JPL	300.00	670	201000
WS–LARC	50.00	1751	87550
WS–MSFC	0.31	1120	347
WS–JSC	0.01	717	7
TOTAL			1325704

Communications Cost

Option	Mbps*Miles	$/Mbps/Mile/Yr	$/Yr
1	359558	10	3,595,580
2	1325582	10	13,255,820
3	1325704	10	13,257,040

Figure 3.3–10

3.3.9 Smoothing Cost

It is important to note that this is not an SSDS function, and will not be reflected in the SSDS design. It is necessary to consider this to understand cost differences between centralized vs distributed system because centralized system performs the smoothing operation implicitly. This cost is only applied in the cases where smoothing is assumed.

3.3.9.1 Smoothing Cost Model

It is assumed that the smoothing will be done using erasable optical disks. The cost model for this function is the same as the model for the archive. Only the parameters differ.

3.3.9.2 Actual Smoothing Cost

Actual Requirements

r = 100 Mbps
A = 120 Gbytes

Therefore, for each option, the fixed cost for archival is $0.5 Million and the recurring cost is $0.8M per year.

3.4 Sensitivities

The major sensitivities in this system are with respect to communications and storage costs.

3.4.1 Communications Sensitivities

Although a detailed analysis of the ground communications design is outside of the scope of the SSDS study, the fact remains that this element will be an integral portion of the ground system. Fiber optic communications appears to be the wave of the future, however at this point the costs are highly uncertain. For purposes of this trade study, the parameter XI

($/mbps/mile/yr) is used to measure the state of the art of communications. Current communications costs for the White Sands to Goddard link have been calculated to be about $26/mbps/mile/year. Projections from Fibertrak indicate that this will go down to $8/mbps/mile/year.

Figure 3.4-1 illustrates the overall 10 year costs of the three options as a function of communications cost assuming that no smoothing is performed. The point here is that a centralized system performs smoothing inherently. The advantage of this feature is higher for higher communications costs.

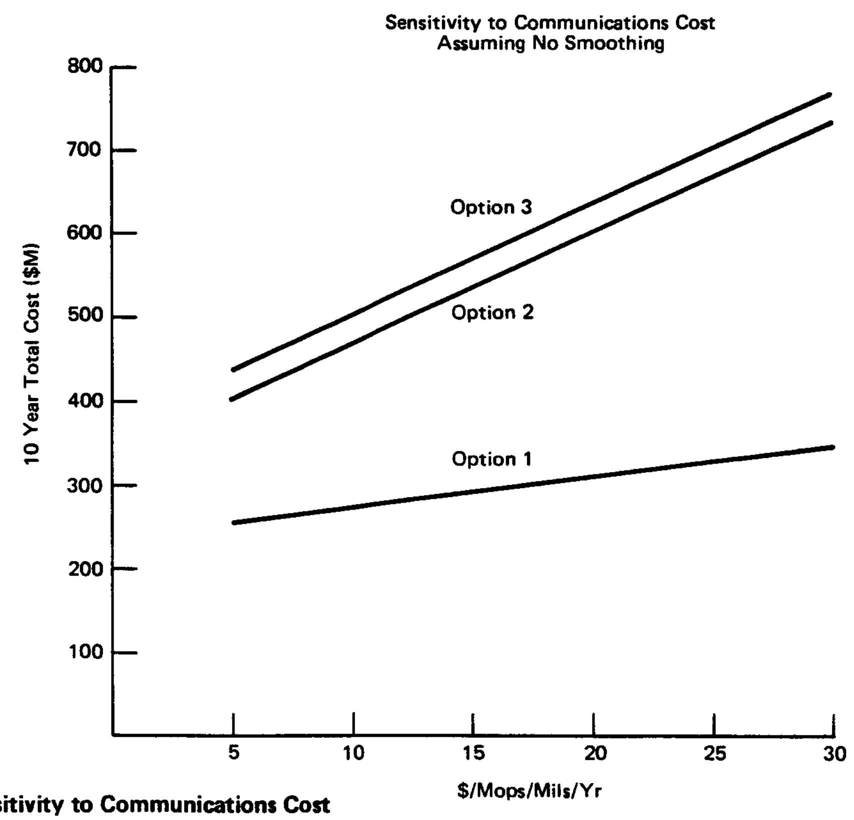

Figure 3.4-1. Sensitivity to Communications Cost

3.4.2 Mass Storage Sensitivities

The model used to derive a parametric description of optical disk based system mass storage costs is provided in section 3.3.6.1. The one parameter which describes the state of the art of read/write optical disks is :

(cost per disk) / ((gigabytes per disk) * (writes per disk))

For purposes of this sensitivity analysis, this variable is known as X2. The key here is that the only optical disks currently available are write once disks. At current prices, X2 = $125/Gbyte/Write. According to the mass storage trade study, it is projected that X2 will go down to $0.45/Gbyte/write. Figure 3.4-2 illustrates the profound impact on the 10 year cost of the system. The actual design of the system will be highly dependent on the state of the art of the optical disk technology. At current prices, optical disks would not be included in the system design.

Advances are being made in the optical disk technology. One key issue is in the area of media which can be erased and re-written many times. If technology advances to the point where disks may be written to thousands of times, then the recurring media cost will be neglible. But how much will these systems cost?

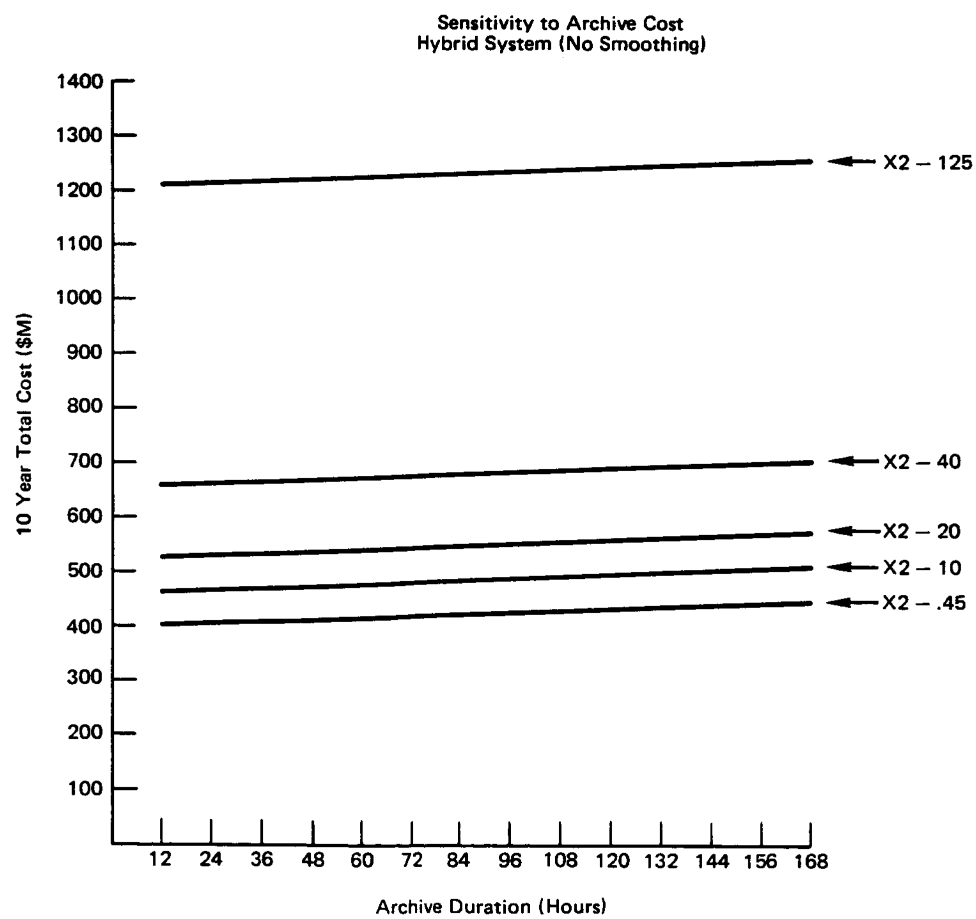

Figure 3.4-2. Sensitivity to Archive Cost

The key point here is that the cost differences as a function of the state of the art of optical disk systems are far greater than the cost differences as a function of the topology option chosen. This by no means implies that cost is an insignificant factor in picking a topology. It simply points out that these differences are not overwhelming, and that other factors should be considered in order to pick a topology which will serve as the cornerstone for the space station ground system end-to-end payload data processing.

4.0 Issues and Recommendations

There are a large number of non-cost issues which are used to help determine which topology best serves the overall needs of the Space Station ground system. Many of these are difficult to relate to cost, and others deal with issues whose scope is larger than the SSDS. Sections 4.1 through 4.3 present a number of key issues and explain how these effect the choice of topology. Based on this information as well as the results of the cost and sensitivity analyses, section 4.4 presents the recommended ground topology for the routing and processing of payload data.

4.1 Physical Proximity to Higher Level Processing

One key issue is the advantage of co-locating Level 0 processing with the high rate missions. Upper level processing is unique to the payload. This processing will be performed at Regional Data Centers, and by definition will be an SSIS function. It is expected that the RDC's will be distributed and, therefore, the advantages of co-location will be gained if the Level 0 processing is distributed likewise. The advantages of co-location, and thus of the hybrid or distributed systems are described in sections 4.1.1 through 4.1.3.

4.1.1 Ease of Access to Level 0 Data and Re-Transmission

One advantage of co-location is that it provides ease of access to the Level 0 storage from the upper level processing.

LANDSAT has had the experience that gaps have been introduced not only by the Space-Ground communications, but also by the ground- to-ground communications. The data is thus shipped from White Sands to GSFC where Level 0 processing is performed to correct for both kinds of problems. High rate missions are the least likely to be able to utilize robust transmission protocols, such as re-transmission, and thus the most subject to have such problems and require re-transmission. Re-transmission over a Local Area Network seems less likely to introduce errors.

4.1.2 Archival and Other Storage Duplication

Depending on the design of the SSIS, it may be possible to use the Level 0 storage (7 day) as a source of data for higher level processing.

At 165 Mb/s average, temporary storage for 7 days will be a significant cost analysis. Significant SSIS cost savings could be achieved if this data store is shared.

4.1.3 Sharing of Other Resources

Depending on the design and implementation of the SSIS (RDC), it may be very possible to share a number of resources between SSDS and SSIS. Specific resources considered here may be high performance processors, spare parts, hardware maintenance personnel, software maintenance personnel, and operations personnel.

4.2 Evolution to ACTS or TDAS Environment

It is expected that some time in the future, relay satellites will have the capability to downlink data directly to distributed earth terminals. This would tend to favor a hybrid approach, as direct downlinks could be used to the Level 0 sites, saving on communications costs. Once a centralized facility is established, it may be programmatically very difficult to migrate to a more distributed environment, given the investment involved, and especially if the capability is established at White Sands.

4.3 Sensitivity to Requirements

Many of the requirements which drive this study are subject to change. The impacts of changes to these study inputs may be very significant. Sections 4.3.1 through 4.3.4 describe four of these:

4.3.1 High Rate Payload Downlink Format

It has been a study assumption that high rate payloads output CCSDS packets. If this is not the case, the centralized Level 0 processing may be much more complex. In the case of distributed or hybrid option, the high rate payload data processor may be designed to match the downlink format.

4.3.2 The Langley Data Base The data in the Langley Data Base is frequently changing, and probably will continue to change through launch. In light of this, the hybrid option has some distinct advantages. If a high rate mission is added or deleted, the portion of the system which services that payload may be added or deleted, with minimal impact to the rest of the system. On the other hand, the marginal cost of adding a low rate payload is minimized because the resources which service that payload are shared.

4.3.3 Real Time and Quicklook Data

If it is assumed that high rate mission POCC's need the full bandwidth in real time for quicklook data, then one would tend to co-locate the Level 0 processing and the POCC for that mission, to meet the real time requirements. The communications costs would be less a discriminator between the Level 0 architectures since the communications costs would be borne anyway for the POCC's. If this bandwidth is required, then there is no advantage to smoothing and a distinct disadvantage for the centralized approach.

4.3.4 Level 0 Delivery Requirements

It is required to deliver the Level 0 data for high rate missions within 24 hours, as specified in the Langley Data Base. If longer delays are allowed, a centralized system may be preferred. In a centralized system, one could save bandwidth from the Level 0 site to the upper level site by mailing an optical disk.

4.4 Conclusion

Based on the costs and the issues described in sections 3 and 4, the hybrid system has been chosen for the baseline ground system design. The major reasons for this decision are the fact that the cost differences were not overwhelming, combined with the fact that the hybrid system demonstrates significant advantages in the areas of flexibility with respect to changing system requirements, potential overall ground system cost savings, and better potential for future technology insertion.

APPENDIX A

Contents

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
COMMUNICATIONS COST

OPTION 1,3

SA LINKS ______

FROM	TO	MILES	RATE	COST(k)
WS	GS	1728	75	1296
WS	JPL	670	21	141
				1437

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
COMMUNICATIONS COST

OPTION 2I

SA LINKS 1

FROM	TO	MILES	RATE	COST(k)
WS	GS	1728	233	4032
GS	JPL	2289	21	481
				4523

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
COMMUNICATIONS COST

OPTION 2I

SA LINKS 2

FROM	TO	MILES	RATE	COST(k)
WS	GS	1728	466	8064
GS	JPL	2289	21	481
				8545

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
COMMUNICATIONS COST

OPTION 2I

SA LINKS 3

FROM	TO	MILES	RATE	COST(k)
WS	GS	1728	700	12096
GS	JPL	2289	21	481
				12577

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 1

SA LINKS 1

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	220	10	2200
POP1	510	10	5100
POP2	352	10	3520
W	833	.2	166
			10986

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 1

SA LINKS 2

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	216	10	2160
POP1	82	10	820
POP2	245	10	2450
WS	1001	2	200
			5630

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 1

SA LINKS 3

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	176	10	1760
POP1	64	10	640
POP2	233	10	2330
WS	1036	.2	207
			4937

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 2

SA LINKS 1

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	220	10	2200
POP1	510	10	5100
POP2	352	10	3520
GSFC	494	.2	99
			10939

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 2

SA LINKS 2

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	216	10	2160
POP1	82	10	820
POP2	245	10	2450
GSFC	578	.2	115
			5545

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 2

SA LINKS 3

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	176	10	1760
POP1	64	10	640
POP2	233	10	2330
GSFC	587	.2	117
			4847

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 3

SA LINKS 1

LOCATION	BUFFERSIZE (GBITS)	COST PER GBIT ($K)	COST ($K)
SS	220	10	2200
POP1	510	10	5100
POP2	352	10	3520
			10840

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 3

SA LINKS 2

LOCATION	BUFFERSIZE(GBITS)	COST PER GBIT ($K)	COST ($K)
SS	216	10	2160
POP1	82	10	820
POP2	245	10	2450
			5430

SPACE STATION NETWORK TOPOLOGY
TRADE STUDY
BUFFER COST

OPTION 3

SA LINKS 3

LOCATION	BUFFERSIZE (GBITS)	COST PER GBIT ($K)	COST ($K)
SS	176	10	1760
POP1	64	10	640
POP2	233	10	2330
			4730

IV. COMMUNICATIONS STANDARDIZATION

COMMUNICATIONS STANDARDIZATION TRADE STUDY

1.0 Trade Study Definition

1.1 Background

The SSDS will develop as a combination of ground and space data networks connected through a communication link that involves current and future satellites, remote-user Ground Stations and onboard stations. Communications will be by way of existing and future networks for data distribution, serving both Space Station core and user needs. Data paths will involve several network media (e.g., RF, wire, and fiber optics) and protocols (e.g., packet sizes, data rates, and message headers). The SSDS must incorporate existing and emerging communication standards to promote growth and to realize the cost-effective benefits of standardization. This trade study will address the following specific areas related to communication standards:

1) CCSDS and IOS/OSI compatibility issues

2) Use of CCSDS recommendations for packet telemetry and telecommands, telemetry/telecommand channel coding, standard format data unit (SFDU) utilization, and application of CCSDS standard time code formats

3) Identification/recommendation of standards (developed or emerging) for layers 2-7 of ISO/OSI for both space and ground

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1.2 Issues

The following issues are applicable to this trade study:

1. Use of international and national standards including those from the following organizations: International Standards Organization, Consultive Committee for Space Data Systems, American National Standard Institute (ANSI), Consultive Committee For International Telegraph and Telephone (CCITT), European Computer Manufacters Association (ECMA), National Bureau of Standards, EIA ....

2. Use of commercial non-ISO/OSI standards (proprietary protocols)

3. Identifying the need for new standards development

4. Ground and space commonality/migration issues.

1.3 Selected Criteria

The selection criteria are as follows:

- Requirements tradeoffs — the degree to which the option meets the requirements of Task 1 and those derived requirements described in the Standardization Options paper

- Technical feasibility — any inherent technological limitations, e.g., packet switching speeds

- Impacts on SSDS elements — examining and balancing the impacts on major SSDS elements. These are:

- Payload Interface
- On-board LAN & DMS
- Gateways
- TDRS Uplink/Downlink
- Data Handling Center
- Regional Data Center

The options paper summarized a number of requirements from the Task 1 report, and also from other sources and requirements and implications resulting from the Task 1 requirements. These were presented in the options paper according to the ISO/OSI layers. These are summarized in the following section.

1.4 Requirements Affecting Selection of Standards

The SSIS/SCS (per Figure 1-2 includes both SSDS and non-SSDS elements) shall obtain and/or develop standards for customer interfaces in areas such as software, critical/limited payload, health and safety monitoring, man-machine interfaces, command generation, time code, attitude and position data, pointing coordinate systems, data base management systems, graphics displays, data handling/archiving/distribution, documentation, configuration control, cost accounting, data system requirements definition, operations audit trail, etc. When new customer standards are proposed, the SSIS/SCS shall present these standards to a customer panel which will provide an impact statement on behalf of all customers (Task 1, Section 5.3.8.9).

The SSDS shall provide standardized language, protocol, format, and transmission rates for all SSDS and all SSDS subsystems (Task 1, 5.3.8.9).

As a first preference, customer interface standards shall be defined in accordance with the International Standards Organization (ISO) seven layer model for Open Systems Interconnect (OSI) (Task 1, Section 5.3.8.9).

The SSDS shall use, for each of the seven layers, existing internationally accepted standards as a first priority followed by new standards development (within the OSI model framework) (Task 1, Section 5.3.8.9).

The customer interfaces defined within the OSI model shall conform to standards defined and controlled by such sources as:

NBS, National Bureau of Standards

ANSI, American National Standards Institute

ECMA, European Computer Manufacturing Association

CCITT, Consultative Committee for International Telegraph and Telephone

EIA, Electronic Industry Association

CCSDS, Consultive Committee for Space Data Systems

IEEE, Institute of Electrical & Electronic Engineers

When practical, appropriate standards from these sources shall be used at higher layers of the OSI model (Task 1, Section 5.3.8.9).

For customer interfaces, support commercially available standards.

Provide ancilliary avionics and housekeeping data (timing, state vector, RF communication, system status, acquisition of signal/loss of signal, moding, pointing, etc) to the attached payloads and customers (Task 1, Section 5.3.2.4).

The SSIS/SCS network data handling shall be independent of the format or content of the customer data (CRSS, 3.1.4).

Customer data shall be delivered without alteration of its contents. Any artifacts imposed by the data transport service, e.g., data reversal due to communicatons buffering, shall be removed before data delivery to the customer (CRSS, 5.4.3).

Format data in self identifying data units (derived).

Support multiple payloads in a way which minimizes interactions and a minimum of software re-configuration (Derived).

Support an evolutionary expansion of the SS DMS (Derived).

Support the end-to-end BER requirements (10**-6 to 10**-9).

Support quality of transport service (computer quality vs normal quality) (Derived).

Provide real-time distribution of real-time and near real-time data, including Level 0 processing, demultiplexing, buffering, routing, and re-transmission (Task 1, Section 5.3.1.3).

Provide real-time, raw payload data to the customer (Section 5.3.1.1).

Support real-time re-allocation of data distribution resources to help meet customer priorities (Section 5.3.3.3).

Support rapid separation of the downlink/uplink by customer ID (Derived).

Support electronic transmission of data to customers and RDC's (Derived).

Support delivery service (immediate delivery vs store & forward delivery) (Derived).

Support reliability services (verified delivery vs unverified delivery) (Derived).

Support symmetric services (uplink/downlink) (Derived).

Allow or support encryption (Derived).

1.5 Applicable Options

In the description of communications standards options, four options were presented for implementation of an end-to-end standards architecture:

I) ISO Compatible Standards For Local & Wide Area Networks (space & ground) combined with:

a) CCSDS Packets Implemented As An ISO Upper Layer Standard

b) CCSDS Packets & Frames Implemented "Below" Onboard ISO

c) CCSDS Implemented As Alternate Downlink Standards For ISO Layers 1-3

II) ISO Standards Only

Upon subsequent reviews, a consensus developed that the most promising design appeared to be the first (1a). The options paper presented a number of options within each ISO/OSI layer for choices of standards.

2.0 Trade Study Methodology & Approach

This trade study will:

- compare the design with its major alternate implementation options
- examine tradeoffs between implementations of the design
- examine the characteristics of the local and wide area standards that should be used

As noted, there were four major options presented for an end-to-end standards architecture. This tradeoff will provide a high level comparison of the options. There are several issues within the proposed design option which will be discussed. While this study was not intended to select specific standards for the LAN and WAN, this trade will characterize the desired choices. The choice of standards is driven by the end-to-end topology and the needs of each subnetwork, rather than the inverse.

2.1 Implementation Options

The following provides an overview of the proposed implementation of an end-to-end standards architecture that is consistent with option 1a identified in section 1.5.

The CCSDS Packet Standard is implemented as application layer data. Each packet is delivered to the Space Station local area network. The On-board LAN implements some portion of ISO layers 1-7. All headers are added and removed by the on-board LAN. The layer 4-7 ISO protocols thus apply from one on-board instrument to another. At the downlink gateway, the CCSDS Telemetry packets are reassembled into the original source packets. These are framed and encoded. Framing is done asynchronously to the packetization, i.e., the boundaries do not line up.

An inverse process occurs on the ground. The codeblocks are de-coded, and frames are removed. The framing/de-framing process synch's on the frame synch code. Packetization and packet recovery is performed using the frame pointer to the first packet header, using the packet size data in the packet header to recover the original packet (which may be spread through several frames). The source packets are then transmitted over the ground wide area network.

The above is a version of the first option for implementation of an end-to-end standards architecture. This proposed design will be compared with two of the three other options presented in the options paper. The fourth option in the options paper was to only utilize ISO standards. This option was presented for logical completeness. Existing ISO standards are not suited to the needs of the space-ground link, as noted in the options paper, and thus this option implies development of entirely new standards, not a modification of existing standards. Since this is at best speculative, this fourth option will not be discussed further in this section.

2.1.1 Requirements Tradeoffs

SSDS requirements affecting the selection of communications standards has been summarized in the options paper. The options will be compared with respect to how well key requirements are met.

In their original form, none of the options support the following services as customer selectable options:

- o quality of transport service (computer quality vs normal quality)
- o delivery service (immediate delivery vs store & forward delivery)
- o support reliability services (verified vs unverified delivery)
- o support symmetric services for uplink/downlink

This does not provide a discriminator between the options.

Using a strict interpretation of the requirements, the proposed design does not meet the following requirements:

- o The SSIS/SCS data handling shall be independent of the format or content of the customer data (CRSS)

- o The data network shall be able to transport and deliver data sets intact, without having any knowledge of their internal format or content (CRSS, 2.2.3.4)

These requirements are not met since the CCSDS formats are implemented as part of the application data. This is interpreted to mean just that - the headers literally treated as data and not examined by the data system. This may not be the case if the format were implemented as a standard at some other level. Whether it makes any practical difference to implement the formats as application, presentation, or transport standards will be discussed in the next section.

The requirements above are met by the other options since the SSDS can depend on using data system required headers to route the data.

The other requirement not met is to provide communications services symmetrically over the uplink/downlink. The desired autonomy of the space station extends to processors onboard to be able to send requests for ground based resources without human intervention — computer-to-computer communication. This requires such services as verification of receipt and retransmission, services normally associated with uplink telecommands.

Furthermore, the autonomy of the space station is expected to increase over time, with functions migrating from ground to space. It is desirable to accomplish this migration without requiring extensive modifications to the software of functions which intercommunicate.

This implies:

- o providing all services, (such as verified vs unverified delivery) in both directions

- o use the same packet/frame format in each direction (currently the formats are different for the uplink/downlink)

- o implementing an addressing scheme that can be used for either space or ground

2.1.2 Impacts On SSDS Elements

The payload always has a packet format, whether it is in the laboratory or in the Space Station or platform. This simplifies testing. This is not true for the other two options. The same is true for the core interfaces.

The on-board LAN must carry the CCSDS packet header information, while the other two options do not. Since the source packets are long, this does not appear to be significant. For example, take two sample packets lengths of 12, 800 bits and 4000 bits (taken from the Gamma Ray Observatory). In this case, the overhead for the primary header is .375% and 1.2%, and the secondary header (ancilliary data) is 1.375% and 4.4% respectively.

The on-board gateway (uplink/downlink) is less complex for the downlink for this option than for the other two options. In the design, the gateway must re-assemble the original source packet (and remove the on-board LAN headers) and perform the framing and channel encoding. In the other two options, the gateway must also create each packet including adding the relevant ancilliary data. While this approach has been used by some spacecraft (packetization by central processor), it actually can reduce the value of the packet telemetry approach. For example, one might add the same ancilliary data to each packet, and make all the packets of the same length as opposed to making these items customer or payload specific. Another result is that the payload interface changes, as noted above.

The on-board gateway, on the uplink, must read the packet destination ID and incorporate this into the ISO headers. The complexity appears slightly greater for the proposed option than for the other options since a translation must be done between the application address and the on-board location.

The ground gateway for the design, and the ground processing required to route downlink data is greater for the proposed design than for other options. A translation must be done for both uplink and downlink between the application ID and the ground location.

The ground reception point must act as the intelligent interface or gateway between the data distribution network and the TDRSS uplink/downlink. With multiple TDRS and two NGT the mapping between TDRS channels will be very dynamic. The COP, POP, or SS might be using one NGT at one time, and other at another time. Scheduling all this may be very difficult, so that the right data goes to the right customer or RDC.

The gateway, in the DHC will be required to perform:

- o data capture
- o interface to both NGTs
- o separate SS from non-SS data (on a scheduled basis)
- o remove the CCSDS frames and channel coding
- o read the source application ID on the CCSDS Packet
- o from a look-up table maintained by Ground Facilities Management, determine the destination
- o Based on the destination, send the data to the right port for that data. Different options exist for network switching and routing the data depending on the data type and characteristics.

- Provide the physical, data link, and network interfaces to the data distribution network or subnetwork used, e.g.

  - if the data is sent on a fixed or scheduled point to point link through a mux, send the data to the right mux port

  - if the data is sent on a circuit switched link, interface to the circuit switch and set up the call

  - if the data is message switched, add the necessary data link and network headers (based on the inferred source ID) and send it to the message switch

  - if the data is to be packet switched, add the necessary data link and network headers, set up a virtual connection to the endpoint, and transfer the data

The inverse functions would have to be performed for the uplink. That is, packets or data streams would be routed to the DHC, these would be put in the right format for the uplink. One might apply the on-board ISO headers at the DHC, or more likely at the on-board gateway as noted above. The data volumes for the uplink are much less, requiring less processing.

All these functions are needed to meet the requirement that the customer be able to interact with the payload in essentially the same manner as in the laboratory. Thus one is required to have an end-to-end session between the payload and the ground control point.

The functions at the DHC are somewhat simplier for the other options since they assume a direct translation between the uplink/downlink protocols and the on-board and WAN protocols. Protocol conversion is required but it may be possible to do this without scheduling or a table lookup.

2.2 How Should Standards Be Implemented?

The first issue on implementing the proposed design is whether the CCSDS standards are implemented as part of the application data or as application, presentation, or transport layer standards.

One possible difference in terms of requirements is that two additional requirements are met if the formats are implemented as standards rather than part of the application data:

- the SSIS/SCS data handling shall be independent of the format or content of the customer data (CRSS)

- the data network shall be able to transport and deliver data sets intact, without having any knowledge of their internal format or content (CRSS, 2.2.3.4)

The practical impact of this view is programmatic:

- If the formats are truly implemented as "application data" there will be no means to insure that the customers actually use these formats. In fact some advocate that customers may be using many formats.

  - Taken to the logical extreme, this view could prevent the SSDS from even delivering the data. The SSDS is dependent on being able to read the source application ID, for example.

- If the packet formats are implemented as required SSDS standards, then:

  - the SSDS must certify that the payloads are in fact formatting the data properly

  - the SSDS may consider providing source code to do the formatting of the customer data

Accordingly, it is recommended that the telemetry formats (present or modified) be adopted as SSDS standards. The only technical impact occurs if the telemetry standard is implemented as a transport level standards. In this case, it would be implemented in the NIU. This would also mean that the packetization would no longer be done by the payload but by the SSDS. However, instead of being done by a central gateway (as discussed previously) the telemetry packetization is being done in a decentralized manner.

2.3 What Standards Should Be Used?

We consider standards applicable to three major areas:

- Flight segment local area networks
- Terrestrial local area networks
- Terrestrial wide area networks

This differentiation is essentially driven by limitations of underlying data transmission media and switching equipment. More uniformity of standards is feasible in the flight segment LAN's while a diversity of standards must be tolerated in terrestrial LAN's. Bandwidth contraints and limitations of commercially available switching equipment are significant constraints for the terrestrial WAN's and LAN's while realiability and availability of space-qualified hardware are more significant constraints for the flight segment LAN's. Although higher-levels of the ISO/OSI model are important, standards are still poorly developed and we concentrate on the first few layers (physical, data link, network) in this section.

The TDRSS and direct user links essentially are noisy gateways between these networks. The design of these links is driven both by the limitations of the underlying physical links and requirements for protocol translation. Needs for user transparency, efficient high speed protocol translation, and eventual migration of ground functions to the flight segment, dictate that these standards and related addressing conventions be as uniform as possible across all three sets of network components.

2.3.1 Flight Segment Local Area Networks

A major tradeoff for flight segment LAN's is in physical media, in particular whether fiber optics should be used in place of traditional coaxial, twisted pair, or multiline electrical bus structures. Use of fiber optics for space segment LAN's has a number of advantages, including feasible bandwidths of up to 10 gigabits/second and immunity to electromagnetic interference. However, there are a number of disadvantages. Feasible topologies for fiber optics LAN's are pretty much limited to star and token ring configurations. This limitation will probably continue until research in methodologies for tapping fiber optics cables leads to new connector solutions. Unfortunately, there are no widely accepted standards for fiber optics bus protocols and it seems likely that NASA will have to create its own (e.g., the Goddard FODS system) or use a military standard (e.g., MIL-STD-1773).

The primary set of standards likely to be of use for high-level ISO layer flight segment LAN standards are the (1) IEEE 802 family of protocols which include multiple physical link protocols united by a common data link protocol (IEEE 802.2) or (2) the ANSI X3T9.5. Although the collision sense and token ring protocols associated with IEEE 802 may not be appropriate under the constraints of flight hardware and the bandwidth requirements of the SSDS, the data link protocol provides the definition of a critical layer of the flight segment LAN which will make ground and flight segment application transparency feasible in the later phases of the Space Station program. Alternatives include use of variants of current avionics system buses (e.g., the MMS bus or MIL-ST-1553). The critical element of this tradeoff is the support of a common set of ground and flight segment protocols which is likely to substantially simplify development and network simulation activities, provide a more uniform development environment, and lay the basis for migration of ground segment functions to the flight segment.

2.3.2 Ground Segment Local Area Network Standards

The ground segment LAN structure is likely to be significantly less uniform than the flight segment LAN. The IEEE 802 family again seems to provide the most straight forward set of solutions, since they provide a broad set of physical link layer solutions, and have been implemented on most major vendors' processors. The IEEE 802.3 protocol (Ethernet) provides adequate bandwidth and response characteristics for workstations, while the IEEE 802.4 token but protocol provides a more predictable response pattern suitable for control networks. Additional physical layer protocols (e.g., fiber optics protocols) can be provided for enhanced bandwidth, but maintaining the same data link layer protocols.

2.3.3 Wide Area Network Standards

The major issue associated with wide area network standards is feasible bandwidth. A leading candidate for an SSDS wide area standard is the X.25 packet standard. Current commercial implementations of X.25 provide service at rates up to 56 kilobits per second. Although higher data rates are feasible, the bandwidth of X.25 is constrained by feasible switching rates, buffering requirements, and handshaking procedures. It is unlikely that rates over a megabit per second can be supported within the forseeable future. For example, support of a 50 meagabit/second X.25 data rate with maximum length X.25 packets requires hardware capable of switching a packet every 20 microseconds, a requirement not easily filled with existing hardware without extensive use of parallelism. Buffering associated with maintaining virtual circuits and handling transmission errors at these rates presents similarly difficult problems.

Alternatives essentially are point-to-point links (such as are currently provided for high-rate NASCOM services) or circuit switched service. The weaknesses of these services are their lack of full error correction, and relative lack of rapid route dynamicism in response to system faults and user requests for services.

A major tradeoff for the SSDS thus involves the use of packet standards for wide area networking versus relatively static switching mechanisms. For example, links between the White Sands DHC and the Regional Data Centers are likely to be relatively static and not require sophisticated dynamic or alternative routing. Circuit switching standards may be appropriate. Another feasible alternative is to define multiple classes of X.25 services, removing elements of the X.25 protocol (e.g., dynamic routing or acknowledgement services) in order to achieve satisfactory performance for high data rates. This would be more akin to a message switching or datagram ("connectionless") approach.

The high rate experiments (300 Mp/s) may or may not be sent in this form of telemetry packets. Wide area standards for this data may be limited to transport (e.g., statistical multiplexing) as opposed to switching (network) standards.

3.0 RESULTS

3.1 Implementation Options

The first option (CCSDS packets implemented as an ISO upper layer standard) is recommended since it appears to have the best fit with requirements and the most balanced set of impacts. However, some changes must be made to how the option is implemented.

3.2 How Should Standards Be Implemented?

The telemetry formats (present or modified) be adopted as standards at some level of ISO structure above the transport layer. This will meet the needs for programmatic verification of the formats but still meet the full range of requirements.

The available standards should be selected so that they:

- provide all services, (such as verified vs unverified delivery) in both directions
- use the same packet/frame format in each direction (currently the formats are different for the uplink/ downlink)
- implement an addressing scheme that can be used for either space or ground

3.3 What Standards Should Be Used?

For the ground segment it appears feasible to adopt an evolutionary approach, expanding the quality of services as packet switching technology improves. A distinction between high and low data rate services which is technology-dependent could be adopted; high data rates would simply be defined as those for which standard X.25 services could not be provided with off-the-shelf switching equipment. High data rate users would be limited to non-dynamic services although they would have access to low rate command and data transfer channels which would provide fully transparent packet network support. As switching technology improves (or as new high performance packet standards are introduced) further capabilities for high rate service could be introduced with the net effect of removing the distinctions between high rate and low rate services.

4.0 Conclusions, Recommendations & Issues

In their current form, none of the options support the following services as customer selectable options:

- o quality of transport service (computer quality vs normal quality)
- o delivery service (immediate delivery vs store & forward delivery)

The feasibility of modifying existing standards so that the above services are supported.

The selection of the wide area network standards is dependent on the detailed design of the wide area data communications network, which is outside of the SSDS. The issues discussed in Section 2.3 are drivers to this design and interact with the design of the SSDS elements.

V. ONBOARD LOCAL AREA NETWORKING

ONBOARD LOCAL AREA NETWORKING TRADE STUDY

1. INTRODUCTION

The purpose of this trade study is to identify and explore the major issues associated with the Space Station onboard local area network.

1.1 BACKGROUND

A local area network is an information transport system for information transfer between devices. LANs generally provide high-bandwidth communication over transmission media. Multiple LANs may be interconnected by gateways/ bridges providing an interconnecting vehicle for a wide variety of communications devices. The Space Station onboard LAN must provide features such as high performance, modularity, fault tolerance, and evolutionary growth capability, all at low costs.

Local area networks basically consist of transmission media, Network Interface Units (NIUs), and the Network Operating System (NOS) (See Figure 1). The NOS is also discussed in the Distributed Operating System Trade Study.

The transmission medium of a LAN is the element of the network which carries the physical signals between nodes. Options for transmission medium include twisted shielded (TSP) pair, coaxial cable and fiber optics. Concurrent with the Space Station Reference Configuration Document, this trade study assumes that the prime LAN transmission medium for the onboard system will be optical fiber. Optical fiber provides a high bandwidth, highly secure medium for data communications. However, other media are not precluded for specific subsystem and payload controlled back-end local LAN's. The 1.7.1.1 Network Transmission Medium option paper provides media comparisons.

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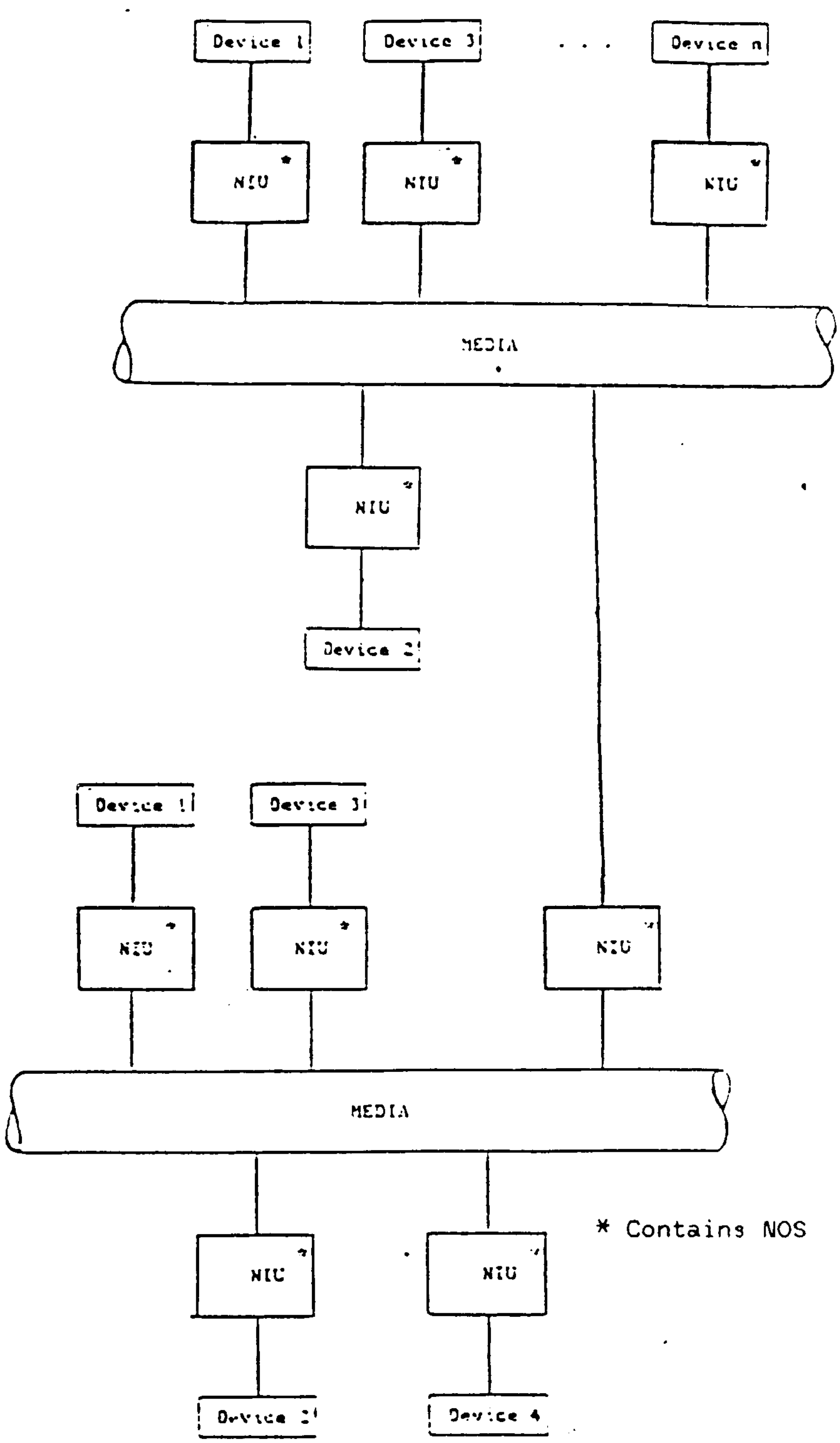

FIGURE 1. Generic Local Area Network

Data system components are attached to the transmission media via Network Interface units (NIUs). The NIU utilizes standard protocols to interface host devices to other host devices. Host devices are attached to the back-end of an NIU and can include SSDS standard processors, user-supplied processors, mass memories, sensors and effectors. Non-homogeneous devices are not necessarily precluded because an "open system" is a major goal. The 1.7.1.2 Network Interface Unit option paper provides additional background.

1.2 ISSUES

Major issues that were considered in developing alternatives for this trade study include the following:

1. Topology - Physical and Logical (star, ring, bus, etc...)
2. Transmission Medium - TSP, optical fiber, etc... (baseband or broadband)
3. Multiple LANs or one global LAN for the Space Station. If multiple, same or different protocols, data rate, medium...? What are the Bridge/Gateway functions?
4. Performance - The LAN must integrate a wide variety of equipment types, ranging from sensors with data rates of less than one bit/sec to experiments with possibly data rates of hundreds of millions of bits/sec. User data rates are given in the mission data base and SSDS function-related data rates were developed in TASK 1.
5. Standardization/commonality - within Space Station and among SSPE's; can impact maintainability costs
6. Protocols and end-to-end compatibility, including use of the Consultive Committee for Space Data Systems (CCSDS) and the ISO/OSI reference model.
7. Media Access Method - Token Passing, CSMA/CD, Laning Poll,...
8. Connection or Connectionless services
9. Are voice, video and data integrated onto one network?
10. What functions does the NIU perform? (versus host?)
11. Back-end interfaces standards versus subsystem unique

1.3 TRADE STUDY CRITERIA

Each alternative was evaluated using the following two groups of criteria:

1.3.1 Generic

The generic criteria across all trades are:

Cost.

- development
- unit
- life cycle

Risk.

- development
- production
- technology readiness

Growth/Technology Insertion Potential.

Standardization/Commonality.

1.3.2 Trade Study Unique

The criteria that are unique to this study are:

Environmental Characteristics.

- Radiation Tolerance
- Other Space Qualified Parameters

Performance and Delay Characteristics.

- connectivity
- reconfiguration

Physical Characteristics.

- weight, power, size

Reliability/Availability/Maintainability.

- fault tolerance

1.4 APPLICABLE OPTION PAPERS

Several Task 2 option papers are applicable to this trade study. The total list is:

- 1.7.1.1. Network Transmission Medium
- 1.7.1.2. Network Interface Unit
- 2.1.3 Distributed Operating System
- 2.2.3 System Growth
- 2.2.5 System Interfaces
- 2.3 System Security/Privacy
- 2.4 Time Management
- 2.5.2 Local/Remote Area Communication
- 2.5.3 Local Area Networks
- 2.6 Network Performance Assessment
- 3.1 Standardization/Commonality

The prime option paper is of course, 2.5.3 Local Area Networks. Also of particular interest are the first two above, 1.7.1.1 and 1.7.1.2. Effectively, the subject LAN Trade Study also covers these areas.

1.5 ALTERNATIVES

The onboard network trade study will be divided into the nine sections listed below. The alternatives in each section are also listed.

(1) Configuration

How is the Space Station onboard LAN configured?

Options:
- Multiple LANs interconnected by bridges/gateways.
- A single Space Station LAN.

(2) Standards

If the Space Station network consists of multiple LANs, should they all follow the same standard?

Options:
- Single standard for LANs
- Multiple standards for LANs

(3) Topology and Media Access Method

What are the topology and media access method for the onboard LAN?

Topology Options:
- Star
- Bus
- Ring
- Mesh
- Star-wired-ring

Media Access Method Options:
- Token Passing
- Slotted Ring
- Register Insertion
- Polling
- Laning Poll
- CSMA/CD

Combinations of the above parameters were evaluated followed by "an assessment of government and industry sponsored technology developments" (Ref.8) resulting in the following options:

- Token Ring
  - ANSI X3T9.5 FDDI
- Token Bus
  - IEEE 802.4 Token Bus
- Laning Poll Bus (logical)
  - AIPS
  - SubACS
- CSMA/CD/TS Bus
  - FODS
- Langley Mesh
- Others
  - SAE/AE-9B

(4) Voice/Video

Are voice and video integrated on the data network or handled separately?

Options:
- Voice/Video/Data Integrated
- Voice/Video handled separately from data

(5) Communications Functions

What functions in terms of ISO/OSI Layers are performed by the communications network?

(6) Network Interface Unit

What functions are allocated and performed by the NIU? Should there be a less complex NIU for simple I/O devices?

Options: - One NIU for all applications (core and payload)
- Less complex NIU for sensors and effectors (core)
- Separate NIU for Customers

(7) Connection - Oriented vs Connectionless Service

Which type of service best satisfies the needs of the Space Station LAN users?

Options: - Connection - Oriented
- Connectionless

(8) Back-end Interfaces

How are devices connected to the backplane bus?
(Considered only recognized external connections, no internal)

Options:

- IEEE 796	- MIL-STD-1553B
- IEEE 488	- MIL-STD-1773
- IEEE 595 (EUR 6100)	- RS-232
	- RS-422
- IEEE 596 (EUR 4600)	
- IEEE 683 (EUR 4100)	- Customer Supplied

(9) Protocols and End-to-End Compatibility

2.0 METHODOLOGY

This trade study incorporated the results of the NIU, Transmission Media, and LAN Task 2 option papers in determining the major issues to be resolved in defining the Space Station onboard LAN and the alternatives in each area. Each of the alternatives was evaluated in order to identify its advantages and disadvantages.

The advantages and disadvantages were identified through the team experience base in the data communications field, interviews with experts, and through literature surveys.

The advantages and disadvantages were then analyzed in terms of the trade criteria in order to arrive at prioritized options for the onboard local area network.

3.0 RESULTS

A summary of all the results in this section is tabulated in a set of decision matrices in Appendix A of this trade study. The following sections discuss those results in more detail.

3.1 Configuration

There are two alternatives for configuring the Space Station communications system. It could be configured as one large local area network spanning the entire Space Station or it could consist of multiple LANs interconnect by bridges/gateways.

One large local area network would provide for easy routing since everything would be connected to the same LAN. This configuration however, has the disadvantage of lower reliability. If there is a link failure, the entire Space Station data communication system could be affected. Another disadvantage is that changes to the system, such as adding a new node or reconfiguring it, affects the whole communications system. Also message delays will generally be larger because there are more nodes contending for a single network.

On the other hand, multiple LANs interconnected by bridges/gateways would require more complex routing, but it would be easier to reconfigure. Adding a new node to a LAN or a new LAN would only affect the local LAN, not the whole Space Station communications system. Multiple LANs are also more fault tolerant; if one LAN fails, the other LANs are still operational. Multiple

LANs would not only enhance security since the payload and core could be on physically different LANs, but also carry a higher net aggregate overall traffic rate. Also, local LAN messages stay in the local LAN and do not impact message rates or performance on the other LANs. Multiple LANs also provide easier connectivity for Space Station build-up and allow a lower level of integration during development and build-up. It is expected that some grouping of payload sensors will be integrated into a single LAN and thus ease their attachment to the total network.

Considering the advantages and disadvantages above (summarized in Table A-1), the multiple LAN communications system is best suited for the Space Station. The multiple LAN configuration allows for easy build-up if the system were designed such that the LANs corresponded to modules. One or more LAN's per module also meets the safe-haven requirements with each bridge/gateway acting as an isolator. This multiple LAN approach is basically consistent with the Space Station Reference Configuration (Reference 5) two network systems — a housekeeping (core) network and a payload network.

3.2 Standards

With multiple LANs on the Space Station, should one standard apply to all LANs, i.e. should they all have the same topology, protocols, etc...? Having a single standard for the onboard LANs satisfies commonality requirements. It also allows for a simpler bridge to provide interconnection between the LANs. Since all LANs have the same protocols, no gateways are required.

This alternative, however, may not be the best solution in the long run. As the data rate requirements evolve with Space Station growth, a single standard for onboard LANs may not satisfy these requirements. Also, this may suppress domestic and foreign customers. If multiple standards were allowed the LANs could be optimized to meet specific requirements. The costs could also be lower since commercial standards may be allowed. Multiple standards also allows for technology insertion in growth; new LANs could utilize state of the art technology.

However, the multiple standards alternative also has some drawbacks. It would require more complex gateways to interconnect the LANs. The gateways must provide flow control and storage since the data rates and protocols may differ. The necessity for gateways could increase the overall net cost of the system.

The advantages and disadvantages of each standard policy alternative are summarized in Table A-2.

Each alternative has some advantages. The single standard for LANs provides the most cost-effective solution while meeting the commonality requirement. Therefore, at IOC, one standard should apply to all LANs. This recommendation, however, does not preclude the use of multiple standards for LANs beyond IOC. Since future requirements may vary, multiple standards in growth are the only practical solution. This also allows for easier technology insertion. As more data becomes available from the customer community, the need for perhaps a second standard for the payload network should be studied.

3.3 LAN Topology and Media Access Methods

The topology of a network determines the manner in which the stations (nodes) of the network are interconnected. There are many ways to interconnect nodes depending on the communications requirements, reliability, medium, and redundancy of the network. The four basic topologies are the star, bus, ring and mesh (see Figure 2). Variations and combinations of these basic topologies can yield useful improvements in performance and should also be evaluated. For a description of the topologies See the Task 2 LAN Option Paper.

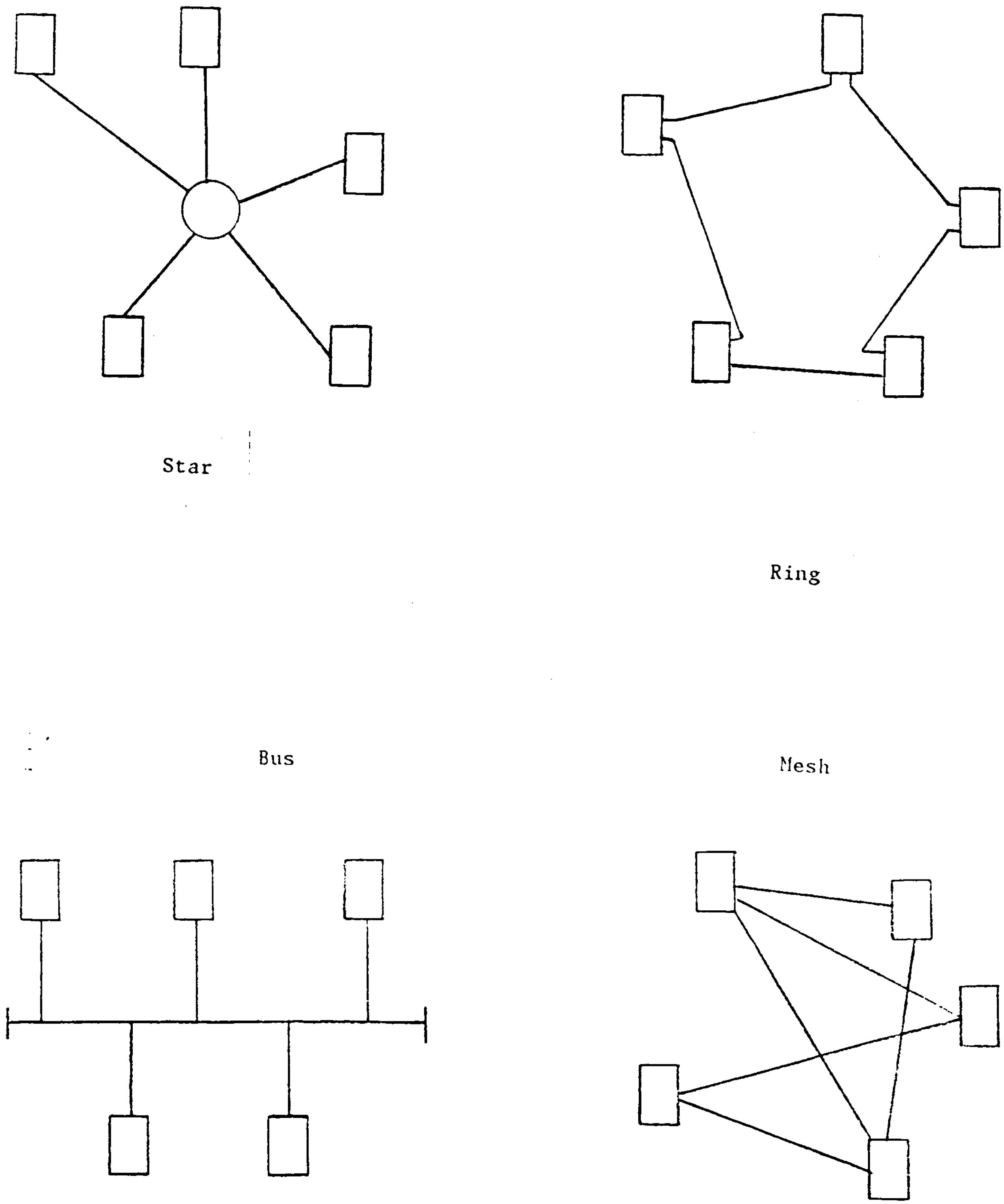

Figure 2. Basic Topologies

The active star will not be further considered for primary use on the Space Station because of its inability to tolerate faults; it relies on the central node (single point of failure). However a star LAN is not precluded for a payload user group with provision for a gateway interface.

The manner in which devices gain access to the medium is determined by the network protocol. Access to the medium may be either controlled or demand access. With demand access techniques such as CSMA/CD, a node attempts to gain access whenever it has a message to send. With controlled access such as token passing or polling a predetermined method is used to award access. The media access protocol options considered here are:

- Token Passing
- Slotted Ring
- Register Insertion
- Polling
- Laning Poll
- CSMA/CD

The performance, reliability, and complexity vary with each protocol. For a description of these media access methods, reference the LAN Option Development.

Some of these media access methods do not meet the Space Station requirements as well as the others. The slotted ring, for instance is wasteful of bandwidth. The register insertion method requires a complex purge mechanism to discard continuously circulating packets, and the polling protocol has a high overhead and is not fault tolerant. CSMA/CD is non-deterministic, (the maximum delay before gaining access to the medium cannot be calculated), has a low utilization at high loads, and does not allow priorities. Due to the major disadvantage of these media access methods, they will not be considered further. It is recognized that other variations on CSMA/CD exist, e.g., CSMA/CA (Collision Avoidance) and CSMA/DP (Dynamic Priority). These tend to be more deterministic, but not as much as a token ring.

The media access protocol and the network topology are interrelated; not every topology allows the use of every media access protocol. Since they are interrelated, they cannot be evaluated separately, and will therefore be evaluated together. The alternatives considered in this trade study are:

Token Ring
- o ANSI X3T9.5 FDDI

Token Bus
- o IEEE 802.4

CSMA/CD/TS Bus
- o FODS

Laning Poll Bus
- o SubACS
- o AIPS

Langley Mesh

Others
- o SAE/AE-9B

A description of each is contained in the LAN Option Paper and Table 1.

The advantages and disadvantages of each of the above alternatives are summarized in Table A-3 of Appendix A.

The LAN speed of each system is not a key factor except for the IEEE 802.4 token bus which typically operates at only 5 Mbps (Ref. 4). This data rate is obviously too low to effectively meet the Space Station requirements. The other networks, however, have essentially the same maximum data rate of approximately 100 Mbps except SAE/AE-9B which has specified the data rate to be greater than 13.6 Mbps.

Table 1: LAN Characteristics

NIU/ MANUFACTURER	IOS/OSI LAYERS	ACCESS METHOD	NETWORK TOPOLOGY	LEVEL OF REDUNDANCY	DATA TRANS.	DATA TRANS.	DATA TRANS.	VIDEO/ VOICE INTERFACE	BACKEND INTER-FACES	POWER REQUIREMENTS	ENVIRONMENTAL SPECIFICATIONS
SubACS/ IBM VHSIC	1-5	Priority arbitra-tion	Multiple buses (passive star)	1-2 (NIU is simplex path is re-dundant)	Fiber Optic wire	Baseband	64 Mbps	None	Navy devices, processors	Approx. 300W	Operating temp.: MIL-STD Rel. humidity: MIL-STD
AIPS/ CSD Laboratory	1-3	Laning Poll	Mesh	1-3 (NIU is simplex network is redundant)		Baseband	3 Mbps (later to 100)	Planned			N/A
FODS Sperry (Breadboard)	1-2 increasing	CSMA/ CD/TS	Bus (passive star)	1-2 (NIU is simplex network is redundant)	Optical Fiber	Baseband	100 Mbps (later to 300)	Possibly	RS232 & a DMA high speed interface	35W (later decreased by 1/3)	N/A
ANSI x3T9.5 FDDI (Standards)	1-2	Token passing	Ring	Counter rotating rings	Optical Fiber	Baseband	100 Mbps	Possibly			N/A
IEEE 802.4 Token Bus (Standards)	1-2	Token passing	Bus			Broadband or Base-band	typically 5Mbps	None			N/A

The cost of the systems does not appear to be a key factor either. The cost of the standard systems, ANSI and IEEE may be slightly less than the others, but the difference will not be significant. The AIPS system is proposed for use throughout the space industry lowering its cost. SubACS is already highly developed thus, lowering its overall cost too. The FODS system may be slightly more expensive due to the complexity of the NIU, and the Langley Mesh may also have a higher cost due to the node electronics. The SAE/AE-9B system is not well enough defined to be evaluated.

The complexity of the systems vary greatly. SubACS, for instance, has very complex NIUs. The SubACS NIU contains over 1100 Integrated circuits. The FODS system will also have complex NIUs due to the dual modes. The Langley Mesh may require complex routing algorithms. The complexity of the other systems is comparable. The complexity effects cost, reliability, risk, and growth/technology insertion potential. An example of the complexity variations is the dynamic range problem associated with the number of devices on a bus.
The complexity of the optical receivers varies as a function of topology. Optical receivers have different sensitivity range requirements depending on the topology of the connecting network. If the strength of the received signal varies, the receiver must adjust its circuitry to properly convert the optical signal to an electrical one.

With point to point links such as those in the ring topology, signal strength varies very little, and simple receivers can be designed. In the linear bus topology, on the other hand, nodes tap into the network and cause a typical signal strength degradation of 1 dB. Addition of several nodes in a network might cause a receiver that does not have automatic gain control (AGC) to erroneously detect a signal.

A passive star network normally does not have this problem because the loss is independent of the number of nodes attached to the star. If the number of nodes that need to be attached is greater than what the system can support and the n node star is replaced by an m node star (with m > n), the additional loss may also require receivers with AGC.

For this reason, the ring topology has an advantage over the bus and passive star. The ring's simpler receivers would be lighter, simpler, and more reliable. The active star generates signals at the central node, so AGC would not be needed there either. Note that even a receiver with AGC will have some limitations. A typical sensitivity range with AGC might be 20 dB or more, but only 2 - 10 dB without AGC.

The fault tolerance/reliability of the onboard LAN must meet the FO/FS/R requirement. Most of these systems provide some means for fault tolerance. ANSI allows nodal bypass switches, counter-rotating rings and ring concentrators. Triply redundant networks exist in the AIPS specification. The Langley Mesh provides redundant paths as does SubACS. The SAE/AE-9B system will also provide fault tolerance but the means have not yet been specified.

However, few of these systems meet the FO/FS/R requirement (AIPS, SubACS and possibly the Langley Mesh). In order to meet this requirement, the redundancy of the other LANs must be increased. The ANSI system, for instance, will operate with one and possibly two faults. In order to guarantee safe operation after two faults, a third ring must be included, ie. a triply redundant network. Similarly, FODS provides redundant networks, but to meet this requirement a third redundant network would have to be included. It is assumed that all systems will be configured with appropriate redundancy levels in order to meet the FO/FS/R requirement.

Consequently, evaluating the reliability/maintainability/availability of the alternatives requires analysis of the reliability of the components. With the IEEE token bus, for instance, the failure of a node adversely affects the logical sequencing of the nodes required for token passing on a bus. The FDDI, allows wiring concentrators. While providing ease of maintenance and growth technology insertion, the wiring concentrators decreases the reliability of the system; if it fails, the connected network could be disabled.

The passive star used in SubACS and FODS is also a possible central point of failure, but since it has no electrical or moving parts, the chances of failure are much less. While the passive star increases reliability, it decreases growth/technology insertion potential because of the signal division among the nodes. If the number of nodes (m) that need to be attached is greater than the number of ports (n) on the passive star, the n port star must be replaced by an m port star. Passive stars cannot be connected serially due to the power losses. On the other hand, wiring concentrators in a ring may be connected serially since each node acts as an active repeater.

The link access performance of the FODS and FDDI systems (ISO Layers 1 and 2) were analyzed (Reference 13). Some results are presented in Figure 3. These two sub-figures indicate that no significant performance differences in mean throughput and mean service time exist between the two systems. Further comparisons between FODS and FDDI are shown in Appendix B of this trade study.

A major advantage of some systems is standardization. The ANSI system, IEEE 802.4 and SAE/AE-9B are all (or will be) standards. A system which is a standard provides a higher growth potential. Standard systems are also usually lower in cost and risk.

The physical characteristics of these systems are not well enough defined to be compared. The power requirement for the current SubACS system (300 watts) exceed the power specified in the Reference Configuration (Ref. 5). It is likely that the implementation of any of the other LAN systems with the same level of SubACS services would require about the same power level (VLSI technology).

Each alternative was evaluated using the criteria. The criteria were divided into three categories: Cost, status, and technical. The categories were allotted 300, 200, and 500 points out of 1000 respectively. A breakdown of the categories and points scale follows:

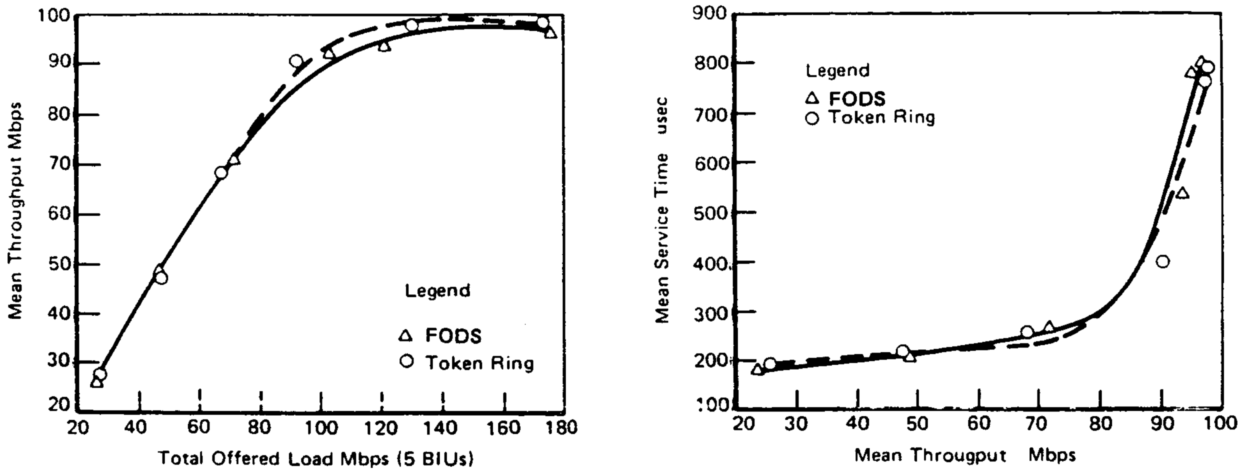

Figure 3. Performance Comparison for the ANSI Standard X3T9.5 Token Ring and the Fiber Optic Demonstration System (FODS) Bus Protocols. Network Parameters Simulated Were: 5 BIUs; 2048 Byte Packet Size; 100 Mbps Transfer Rate

Cost		
Cost	200	
Standardization/Commonality	100	
		300
Status		
Risk (Technology Readiness)	200	
		200
Technical		
Performance	100	
Growth/Technology Insertion Potential	100	
Reliability/Maintainability/Availability	100	
Physical Characteristics	100	
Environmental Considerations	100	
		500
Maximum Points		1000

The LAN evaluation results are shown in Table 2. Additional data are necessary to complete the table.

TABLE 2: LAN EVALUATION

CRITERIA	MAX. POINTS	ANSI X3T9.5 FDDI TOKEN RING	IEEE 802.4 TOKEN BUS	SUBACs LANING POLL BUS (PASSIVE STAR)	AIPS LANING POLL MESH	FODS CSMA/CD/TS BUS (PASSIVE STAR)	LANGLEY MESH	SAE/AE-9B
COST	200	TBS	TBS	TBS	TBS	TBS	TBS	TBS
STANDARDIZATION COMMONALITY	100	100 • STANDARD	100 • STANDARD	70 • STANDARD OPTIONS • USE BY NAVY	70 • PROPOSED FOR WIDE USE IN AEROSPACE INDUSTRY	50	50	100 • WILL BE MIL. STANDARD
RISK (TECHNOLOGY READINESS)	200	75 • UNDER DEVELOPMENT	100 • COMMER-CIALLY AVAILABLE	75 • UNDER DEVELOPMENT	75 • UNDER DEVELOPMENT	75 • UNDER DEVELOPMENT	50 • NOT FULLY DEFINED	TBS • NOT DEFINED
PERFORMANCE	100	90 • LOW RESPONSE TIME AT HIGH LOADS • DETERMINISTIC • SUPPORTS PRIORITIES	20 • BASEBAND-LOW DATA RATES • DETERMIN-ISTIC • SUPPORTS PRIORITIES	60 • AVERAGE RESPONSE TIME AT HIGH LOADS • DETERMINISTIC • SUPPORTS PRIORITIES	60 • AVERAGE RESPONSE TIME AT HIGH LOADS • DETERMINISTIC • SUPPORTS PRIORITIES	70 • LOW RESPONSE TIME AT HIGH LOADS • SEMI-DETERMINISTIC • NO PRIORITIES	TBS	TBS • DETERMIN-ISTIC
GROWTH/TECHNOL-OGY INSERTION POTENTIAL	100	90 • CONCENTRATORS	40 • ADDRESS MAINTENANCE • AGC	60 • PASSIVE STAR	40 • COMPLEX CONNECTIVITY - MESH	60 • PASSIVE STAR	40 • COMPLEX CONNECTIVITY - MESH	TBS
RELIABILITY/ MAINTAINABILITY AVAILABILITY	100	70 • COUNTER-ROTATING • BYPASS • CONCENTRATORS	70 • ADDRESS MAINTENANCE	90 • COMPLEX NIU • REDUNDANT PATHS • PASSIVE STAR	100 • REDUNDANT NETWORKS	90 • COMPLEX NIU • REDUNDANT NETWORKS • PASSIVE STAR	70 • REDUNDANT PATHS	TBS
PHYSICAL CHARACTERISTIC	100	TBS	TBS	TBS • APPROXIMATELY 300W • OVER 1100 IC'S	TBS	TBS 35W DECREASING TO 10W	TBS	TBS
ENVIRONMENTAL CONSIDERATIONS	100	TBS	TBS	TBS	TBS	TBS	TBS	TBS
TOTAL	1,000	*425	*330	*355	*345	*345	TBS	TBS

*SUBTOTAL - DOES NOT INCLUDE COST, PHYSICAL CHARACTERISTICS AND ENVIRONMENTAL CONSIDERATIONS.

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After examining the key advantages and disadvantages of each alternative in Table 2, the highest score was achieved by the ANSI X3T9.5 FDDI system and it appears to best meet the Space Station requirements. ANSI X3T9.5 scores well across all the criteria, a 15% reduction in each FDDI score would still yield the highest total score. It is standardized, deterministic, fault tolerant and has good performance. It handles high data rates (100 Mbps) and does not require excessively long wiring lengths.

As the Langley Mesh and SAE/AE-9B are defined and developed they should be re-evaluated for possible use on the Space Station in growth.

3.4 Voice/Video

Should voice/video and data be integrated onto the same networks?

If voice and video were transmitted on the same network as data, less wiring would be required. This would reduce the cost, but more complex hardware would be required, increasing the cost. The video bandwidth requirements would load the system and possibly inhibit growth.

Alternatively voice/video could be transmitted on one network and data on a separate network. This configuration would require more wiring but simpler hardware since each system would be baseband. Another advantage of this alternative is that the transmitters and receivers could be optimized for each application.

The advantages and disadvantages are summarized in Table A-4.

The advantages of separate networks outweigh the disadvantages for application onboard the Space Station. The electronics for separate networks would be simpler, better known, and, therefore, cost less and have a higher reliability. This configuration also allows for optimization of each system which will provide better performance.

3.5 Communications Functions (ISO/OSI)

The functions performed by a communications system can be described in terms of the ISO/OSI model. The Open Systems Interconnect Model consists of seven distinct layers each performing at set of unique functions. The layered architecture provides flexibility in revising the system. As long as the way information is passed between the layers is not affected, only the appropriate layer needs to be altered to implement the change. This provides the ability to continuously incorporate new technology into the existing system.

The ISO/OSI layers and the possible functions performed by each layer are shown in Table 3. Some layers or some functions designated to a particular layer may not be present in some systems. For example, negotiation for character code conversion (presentation layer) would not be necessary if all systems used the same character set. If the need arises, functions or layers not initially present could be added. Similarly, the Space Station onboard local area network may not require all of these functions. In order to provide a high performance system at the lowest possible cost, only the necessary software services should be provided at IOC. The hardware should be sized at IOC so that other software services may be added when necessary as the system grows. The ISO/OSI functions and their classification of present at IOC or possible incorporated in growth are shown in Table 4. The growth column entries in Table 4 are possible services that may be added after IOC.

The column entries in Table 4 represent a collected view among the study team members and some NASA and other contractor views. It is of note that for IOC a null presentation layer is indicated in Table 4 since data compression (if performed) is assumed to be a user provided function.

ISO/OSI FUNCTIONS	EXPLANATION
7 APPLICATION LAYER	
Connection Oriented	- This type of communication involves initial negotiation of parameters. The following applications are connection-oriented:
-bulk file transfer -virtual terminal usage -message handling services -job transfer and manipulation -stream oriented access to devices	
Connectionless Oriented	- This type of communication involves no initial nego-tiaion of parameters. The following applications are connectionless oriented:
-data collection -outward data dissemination -broadcast / multicast -request / response applications	
Connection / Connectionless Services	- These services are utilized by both types of data transfer
-ID of communicating partners -Establishment of authority to commun. -Authorization of intended partners	
-Application Layer Management	- management of resources at this layer
6 PRESENTATION LAYER This layer provides the means for negotiation of syntax and the need for the following types of conversion.	
- security	- encryption services
- data compression	- data reduction
- character code conversion	- translating to another character set
- graphics syntax conversion	- conversion between different types of graphics
- presentation layer management	- management of resources at this layer

Table 3: ISO/OSI Layers (Part 1 of 3)

ISO/OSI FUNCTIONS	EXPLANATION
5 SESSION LAYER	
- expedited delivery	- a quick pass-through for time-critical data
- multiplexing sessions	- time division multiplexing data
- synchronization	- synchonization points in data
- dialog control	- who speaks, when, how long, half or full duplex
- binding	- setting up the session between two entities
- quarantine service	- provides the means for two communicating entities to pass blocks of data and to agree, in advance, how many blocks are to received collectively before an are transferred to higher layer
- activity management	- allows user to break dialogue into discrete activities which can be suspended,resumed,begun
- session layer management	- management of layer 5 resources
4 TRANSPORT LAYER	
- connectionless management	- management of connectionless service
- connection management	- management of connection-oriented service
- segmentation / reassembly	- breaks/assembles messages into smaller units (segments)
- sequencing	- assembles segments in proper order
- blocking / deblocking	- grouping of small messages into one packet
- header error control	- monitors errors in transport header
- data multiplexing connections	- multiplexing data streams
- expedited delivery	- a quick pass-through for time critical data
- resetting	- indicates to host loss of info. due to subnet crash (1)
- flow control	- prevents data from arriving faster than receiver can handle it
- error detection / control	- checking for errors
- address mapping	- converting logical addresses to physical addresses
- service type conversion	- converting to connectionless or connection-oriented service
- transport layer management	- management of resources at this layer

Table 3: ISO/OSI Layers (Part 2 of 3)

ISO/OSI FUNCTIONS	EXPLANATION
3 NETWORK LAYER	
- routing / switching / relaying	- determines which path to send the packet on
- congestion control	- regulates flooding within the network
- packetization / reassembly	- breaks data into packets and reassembles them
- sequencing	- arranges packets in proper order
- header error control	- monitors errors in the network layer header
- quality of service maintenance	- monitors error rates
- expedited delivery	- quick pass-through for time critical data
- error control	- error checking
- network layer management	- manages resources at this layer
2 DATA LINK LAYER	
- framing	- formats data into frames
- error control / notification	- error checking
- media access	- obtaining control of the media in order to transmit
- flow control	- prevents data from arriving faster than the receiver can handle it
- data link layer management	- manages resources at this layer
1 PHYSICAL LAYER	
determined by medium	- the mechanical, procedural, and electical interface to the medium

Table 3: ISO/OSI Layers (Part 3 of 3)

ISO/OSI layer	FUNCTIONS	IOC	GROWT
7 application	Connection Oriented		
	-bulk file transfer	x	
	-virtual terminal usage	x	
	-message handling services	x	
	-job transfer and manipulation	x	
	-stream oriented access to devices	x	
	Connectionless Oriented	x	
	-data collection	x	
	-outward data dissemination	x	
	-broadcast / multicast	x	
	-request / response applications	x	
	Connection / Connectionless Services		
	-ID of communicating partners	x	
	-Establishment of authority to commun.	x	
	-Authorization of intended partners	x	
	-Application Layer Management	x	
6 presentation	This layer provides the means for the negotiation of syntax and the following types of conversion.		
	- security		x
	- data compression		x
	- character code conversion		x
	- graphics syntax conversion		x
	- presentation layer management		x
5 session	- expedited delivery	x	
	- synchronization	x	
	- activity management		x
	- binding	x	
	- quarantine service		x
	- dialog control	x	
	- session layer management	x	

Table 4: ISO/OSI Functions (Part 1 of 2)

ISO/OSI layer	FUNCTIONS	IOC	GROWT
4	- connectionless management		x
	- connection management	x	
transport	- segmentation / reassembly	x	
	- blocking / deblocking	x	
	- header error control	x	
	- data multiplexing connections	x	
	- expedited delivery	x	
	- sequencing	x	
	- flow control	x	
	- error detection / control	x	
	- address mapping	x	
	- service type conversion	x	
	- transport layer management	x	
3	- routing / switching / relaying	x	
	- lifetime control	x	
network	- congestion control	x	
	- segmentation / reassembly	x	
	- sequencing		x
	- header error control	x	
	- quality of service maintenance		x
	- expedited delivery	x	
	- error control		x
	- network layer management	x	
2	- framing	x	
	- error control / notification		x
data	- media access	x	
link	- flow control		x
	- data link layer management	x	
1	determined by medium		
physical		x	

Table 4: ISO/OSI Functions (Part 2 of 2)

3.6 The NIU

The Network Interface Unit (NIU) is a device that acts as a communications controller to provide data transmission to one or more attached devices (subscribers). This NIU transforms subscriber data rate and protocol to that of local network transmission medium and vice versa. Data on the medium are available to all devices.

The NIU can function as a gateway (providing interconnection of multiple networks that use different protocols) or as a bridge (providing interconnection of multiple networks that use the same protocols). The uses of an NIU in a communications network are shown in Figure 1. The functions performed by the NIU depend upon what ISO/OSI layers are contained in the NIU. (Refer to Tables 3 and 4) One view consists of seven layers in the NIU (shown in Figure 4a) for software portability reasons. Another view, described below, consists of four layers in the NIU (Figure 4b). Further study is needed in this area to determine the optimum configuration.

There are two categories of application layer service elements: Common Application Services Elements (CASE's) and Specific Application Service Elements (SASE's). "Common Application Service Elements provide capabilities required by application processes for information transfer independent of the nature of the application (e.g., setting up an association between application processes, terminating an association between application processes). Specific Application Service Elements provide information transfer capabilities (e.g., file transfer, data base access, job transfer) or capabilities to satisfy the needs of particular application processes." (Ref. 10) In Table 3, CASE's correspond to "Connection/Connectionless Services," and SASE's correspond to all other connection oriented and connectionless oriented elements.

Since the SASE's serve specific application processes, these functions should be provided in the host system. CASE's, on the other hand, are utilized by all applications processes for information transfers. CASE's should also reside in the host. This allows for the initialization of the association between applications processes to be done in the device in which the application resides.

The presentation layer provides the means for negotiations about the syntax of information transfers. Where the syntax is incompatible, mapping must occur. The actual mapping process, however, does not take place in the presentation layer, but in the SASE category of the application layer. The presentation layer, therefore, provides the means for syntax negotiations between communicating entities using different syntax. Since common hardware and software will be utilized as much as possible on the Space Station, incompatible syntax will rarely occur. The presentation layer should, therefore, reside in the host.

The session layer can be viewed as "the user's interface into the network" (Ref. 5). The session layer provides services such as checking the user's right to access the destination and collecting groups of messages so that none are delivered until all have arrived. These services are performed for each user requiring them. When more than one device is attached to the NIU, the presence of the session layer in the NIU would unnecessarily limit the throughput in order to provide these services for each attached device. On the other hand, if the devices perform these functions, several messages could be handled simultaneously (one per device) at this layer. This layer should, therefore, reside in the host.

Unlike the session layer, the transport layer is not user oriented, but provides the end-to-end communications connectivity of the network. Functions such as segmenting messages, multiplexing, and flow control are performed. This layer performs standard communications functions and should, therefore, reside in the NIU.

The network, data link, and physical layer are concerned primarily with routing, media access and the physical connection to the media respectively. These functions are clearly communications functions which should be performed by the NIU not only to alleviate the loading of the host but also to provide a standard communications interface. (See Table A-5)

The division of layers between the host and NIU at the transport-session layers (shown in Figure 5) provides the network transparency, i.e., the host need not be aware of the network topology and protocol. This allows for standardization of the NIU hardware and software. Since the NIU would handle all of the communications protocol, it could support simple digital I/O as well as intelligent hosts. This configuration of the NIU is also functional as a gateway/bridge, which would require only layer 1-3.

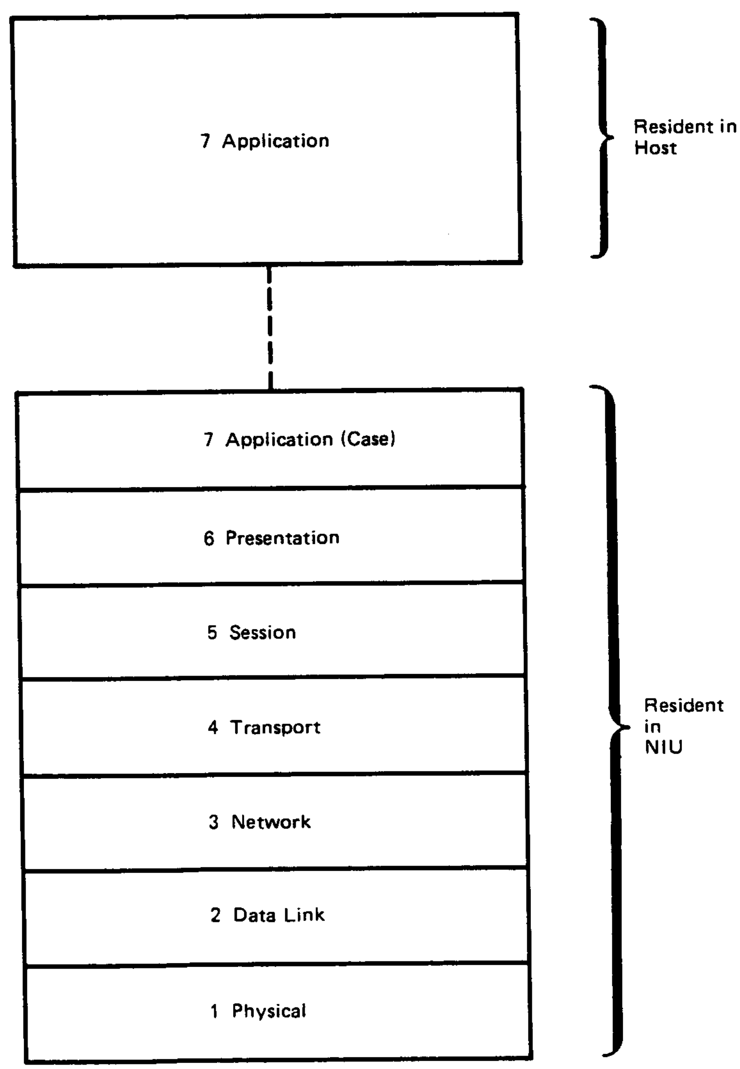


Figure 4a. Option 1 for Division of Layers Between NIU and Host

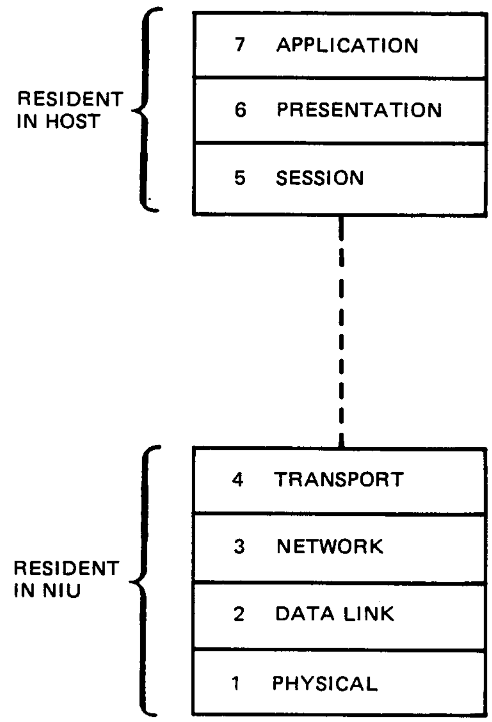
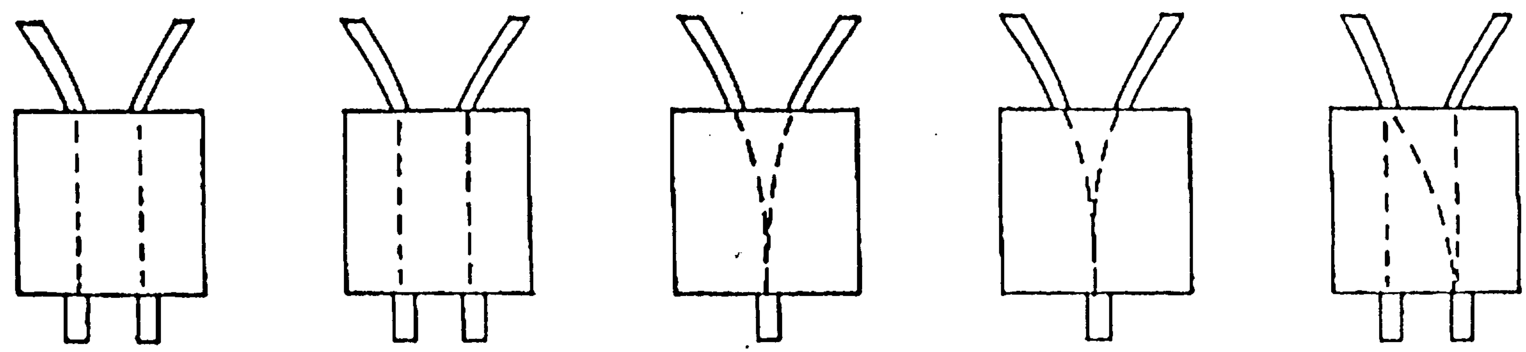


Figure 4b. Option 2 for Division of Layers Between Host and NIU

ISO TRANSPORT LAYER ALTERNATIVES

	CLASS 0	CLASS 1	CLASS 2	CLASS 3	CLASS 4
Error Conditions:	None	Signaled	None	Signaled	Signaled & Detected



CLASS 0	CLASS 1	CLASS 2	CLASS 3	CLASS 4
Connection Data Transfer Segmenting	Connection Data Transfer Segmenting Reset Expedited Data	Connection Data Transfer Segmenting Multiplexing Expedited Data Flow Control (Optional)	Connection Data Transfer Segmenting Multiplexing Reset Expedited Data Flow Control	Connection Data Transfer Segmenting Multiplexing Reset Flow Control Error Control Expedited Data Inactivity Control Checksum (Optional)

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Figure 5: ISO Transport Layer Alternatives

The NIU shall also time-stamp all messages. This is further discussed in the Time Management Task 2 Option Paper 2.4.

3.7 Connection Mode

There are two alternative modes of connection for networks, connection-oriented and connectionless.

Connection-oriented service involves the initial setup of an association between the parties involved before actual data is sent. Once the association is established, it is held for the duration of the transfer. Connection-oriented service "allows for negotiation of parameters and options (such as grade of service). It provides a context for sequencing and flow control of transmitted data units, and it has a clearly distinguished lifetime". (Ref. 3, p. 15) Connection-oriented service provides the advantage of preallocating resources. At transfer initiation, if the resources are not available the message is not sent. This, however, requires more overhead than connectionless service in order to initialize the transfer. Connection-oriented service also allows for error detection and retransmission requests earlier than connectionless service (because sequencing can be done in layer 3).

Connectionless service requires no negotiation of parameters at the time the service is accessed. Each party has "knowledge of the parties with which it may communicate" and "has the explicit knowledge of the characteristics of the service it can expect to be provided with each invocation of the service". (Ref. 7) Each unit of data is independent and self-contained.

Connectionless service uses less bandwidth since there is no initial transfer setup. Another advantage is that connectionless protocols are simple to implement. Error control and sequencing must be provided at a higher layer (layer 4) since each packet is sent independently. This however, should not be a major disadvantage on Space Station since the LAN will provide a robust transmission medium. (The advantages and disadvantages are summarized in Table A-6)

Connection oriented service at the Data Link layer implies sequencing and error control at this layer. Due to the robust nature and low bit error rate of the transmission medium, these services need not be performed at layer 2, but can be provided at a higher layer (layer 4). Therefore, connectionless service at the Data Link Layer will provide reliable yet efficient communications at this layer.

Connection oriented service at the network layer allows large networks (such as multiple LANs interconnected by bridges) to be operated as one large network with deterministic global resource allocation. When routed, each packet of a message follows the same path. Each packet transmitted through a connectionless network layer is routed independently. For the onboard LAN, connectionless service at the network layer will provide efficient services with less overhead.

At the transport layer, connection oriented service implies end-to-end flow control, sequencing, and error checking. Since these essential services are not provided by the connectionless network and data link layers, the transport layer should be connection-oriented. Of the ISO Transport Layer classes of service shown in Figure 5, Class 4 will provide timely and reliable data transfer for mission critical data. The functions available with Class 4 service include data transfer with segmenting, multiplexing, error detection and recovery, flow control, and expedited data transfer.

Class 2 service, which provides for data transfer with segmenting and flow control, may be satisfactory for sensors with over-sampled or perishable data. For voice transfers, Class 2 should also be adequate since humans can compensate for minor transmission errors. Offering two classes of service at this layer may, however, may be more inefficient than only offering the more reliable Class 4 service due to the greater software complexity of offering two classes of service. The Class 4 service proposed by NBS may be more suitable as it supports both connectionless and connection-oriented Transport service. The current development of NBS standards for the Transport Layer should be followed for possible application to the Space Station.

The session, presentation and application layers support both connection and connectionless service in order to provide uniform service across these layers.

A connection-oriented session layer allow for preallocation of buffers. If the buffers are not available the transfer can be suspended at these higher layers. A connection-oriented transport layer provides the essential error control and sequencing and also provides a higher throughput by allowing a connectionless network and data link layer.

3.8 Back-End Interfaces

How are devices attached to the NIU or SDP (Subsystem Data Processor)?

There are many standard external interfaces, parallel and serial, currently available. The interface alternatives include:

Parallel Interfaces

NTDS, Navy Tactical Data System
IEEE - 488, General Purpose Interface Bus

Serial Interfaces

RS-232
RS-422
MIL-STD-1553B
MIL-STD-1773
MIL-STD-1773 (Additions)

Other Commercial/Spacelab
(CAMAC External Interfaces)

IEEE-595
EUR-6100

IEEE-596
EUR-4600

IEEE-683
EUR-4100

CAMAC is Computer Automatic Measurement and Control

The above alternatives for back-end interfaces are characterized in Table 5.

The advantages and disadvantages of each are summarized in Table A-7 in Appendix A of this study. The Spacelab set is not tabulated in the table but are obvious candidates particularly for payload customers.

The NTDS interface is used in many naval systems. This interface protocol requires a large amount of overhead with handshaking after each word. Because it is tailored to navy tactical devices requires large bundles of wire, and has high overhead, this interface should not be used on the Space Station.

The IEEE-488 interface is widely used with commercial test equipment. Asynchronous transfer is allowed with handshaking after each byte. Because of its wide use and relatively high data rate (8 Mbps), this interface could be used on Space Station but a serial interface would provide the same capabilities over longer distances with less wire and less overhead.

Of the serial interfaces, RS232 and RS422 are used to allow interconnection of terminals, computers and peripherals to telecommunications equipment. These interfaces have limited length and require multiple lines. RS232 also has low data rates.

The MIL-STD-1553B, on the other hand, operates at 1 Mbps, has no specified maximum length (determined by cable length, number of terminals and number of stubs), and uses only one wire. This is a military standard used for avionics systems and supported by commercial vendors. It is well defined and should be able to accommodate a large number of sensors and effectors as well as standard data processors, etc...that will be used on Space Station. A 1553 like interface is currently in use on the Shuttle (MIA).

MIL-STD-1773 (planned release date end of 1985) specifies the fiber optic version of MIL-STD-1553. This interface could also be utilized on Space Station, but the 1773 provides no benefit over the 1553B interface.

Table 5: Back-End Interfaces

INTERFACE	METHOD	DATA TRANSFER RATE	MAXIMUM LENGTH	GENERAL USE
NTDS	PARALLEL 16/32 BIT WORD	6.0 μsec PER WORD MAXIMUM 5.3 Mbps	50 FEET	NAVY TACTICAL DATA SYSTEM
IEEE-488	PARALLEL 8 BIT	1 Mbyte PER SECOND	15 METERS	COMMERCIAL TEST AND DATA ACQUISITION EQUIPMENT
RS-232	SERIAL	20 kbps	50 FEET	INTERCONNECTION OF DATA TERMINAL EQUIPMENT TO TELECOMMUNICATIONS EQUIPMENT
RS-422	SERIAL	100 kbps @ 1,200m 10 Mbps @ 100m 1 Mbps @ 15m		INTERCONNECTION OF DATA TERMINAL EQUIPMENT TO TELECOMMUNICATIONS EQUIPMENT
MIL-STD-1553B	SERIAL	1 Mbps	NOT SPECIFIED	AIRCRAFT INTERNAL TIME DIVISION COMMAND/RESPONSE MULTIPLEX DATA BUS
MIL-STD 1773	1553 ON OPTICAL FIBER-SERIAL	1 Mbps	NOT SPECIFIED	AIRCRAFT INTERNAL TIME DIVISION COMMAND/RESPONSE MULTIPLEX DATA BUS
IEEE-595 EUR-6100	BIT AND BYTE SERIAL	30K WORDS/SEC(BIT) 100K WORDS/SEC(BYTE)	1 KILO-METER	PROCESS/EXPERIMENT MEASUREMENT AND CONTROL (CAMAC)
IEEE-596 EUR-4600	PARALLEL	UP TO 500 KWORDS/SEC	NOT SPECIFIED	PROCESS/EXPERIMENT MEASUREMENT AND CONTROL (CAMAC)
IEEE-683 EUR-4100	BLOCK TRANSFER	SAME AS 595/596	NOT SPECIFIED	PROCESS/EXPERIMENT MEASUREMENT AND CONTROL (CAMAC)

CCSDS PACKETS STANDARD IN ISO UPPER LAYER

LOGICAL VIEW

VGZ246

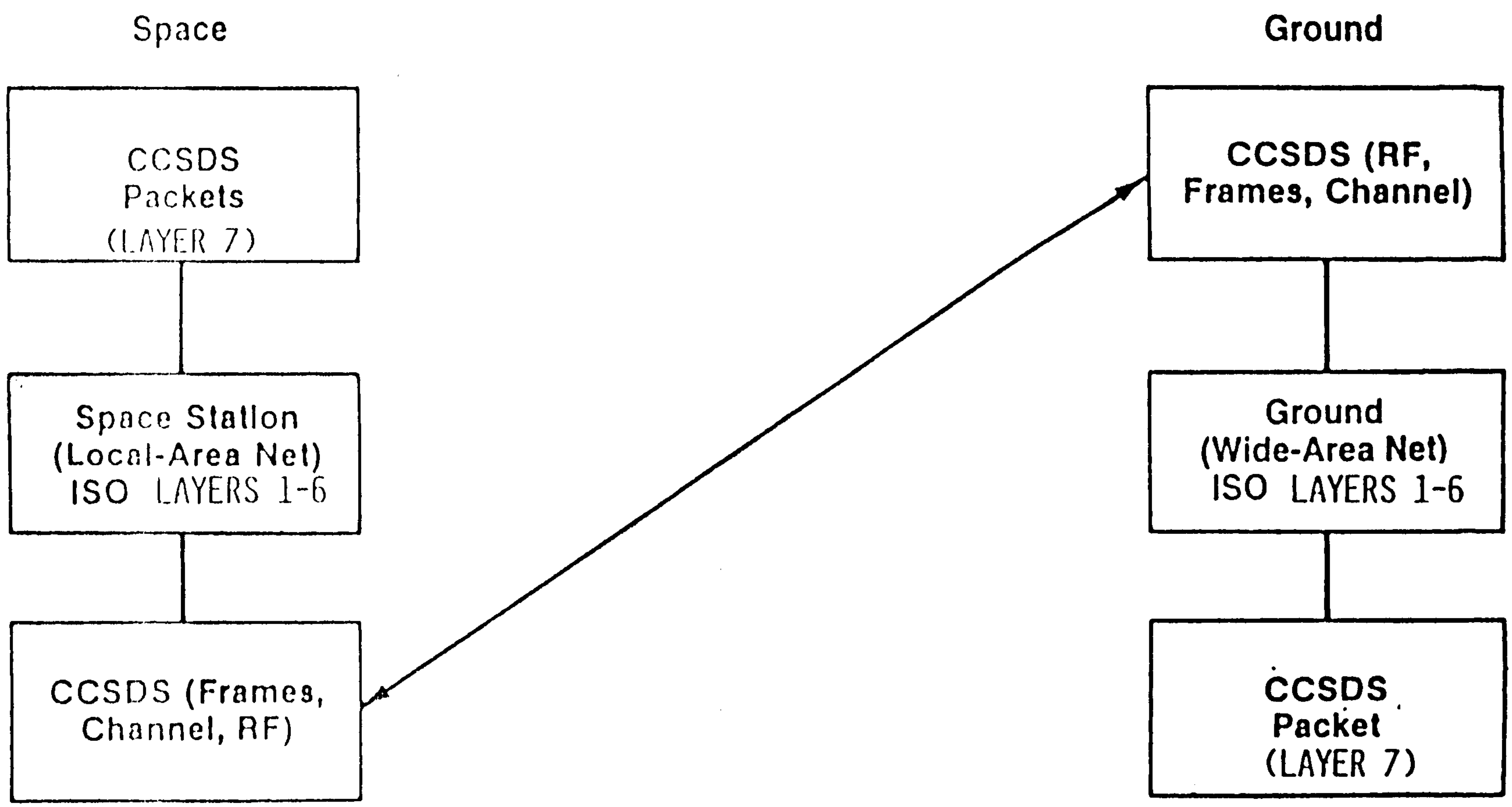

Figure 6: CCSDS and ISO/OSI

Additions to the 1773 standard are currently being developed which would encompass a dual speed standard, 1 Mbps for control and 10 Mbps or 20 Mbps for data transfer. The development of these additions should be followed for possible use on Space Station.

The Spacelab CAMAC interfaces of Table 5 represent the best example of current technology interfaces that have been used and are available for potential payload use on the Space Station.

The development of the Langley Mesh and the SAE/AE-9B network should be followed and perhaps re-evaluated for possible application to the Space Station Program.

It is recommended that voice and video not be integrated with data on the data network. The cost and complexity of the hardware components currently available prohibits a completely integrated system. However, as this technology develops, it should be further investigated.

The Network Interface Unit (NIU) shall provide standard communications functions at IOC. Two options for configuring the NIU were identified. One option is ISO/OSI layers 1-4, residing in the NIU, and ISO/OSI layers 5-7, which are application dependent, resident in the host, thereby allowing the NIU software/hardware to be standardized. Another option is to have seven layers in the NIU, Layers 1-6 and Layer 7 CASE. This option provides flexibility in growth since a minimum amount of software would be ported to heterogenous processors. Further study is required in this area to determine the optimum configuration.

As a result of this LAN study, there is no evidence that, once interface standards are established, custom interfaces for payloads could not be allowed if the existing standards are met.

Connectionless service should be provided at the network and data link layers. At the transport layers, connection-oriented service should be provided. The upper layers should support both types of service. As the need arises, the software services in the NIU can be modified and expanded. This allows for reliable, efficient data transfer.

The MIL-STD-1553B serial interface is recommended for use on the Space Station for the back-end interface to the NIU/SDP where long distances are required. This interface will provide 1 Mbps data transfer over a single serial channel. It is a military standard and is widely used in avionics systems. If desired, MIL-STD-1773 could be used.

The IEEE-488 parallel interfaces also provides an alternative for a non-serial interface to the NIU.

The interface set, used in Spacelab (Table 5) are also available candidates for Space Station.

It is recommended that the Space Station onboard LAN conform to the ISO/OSI model. Telemetry packets (CCSDS) shall be transferred through the onboard local area network in the same manner as other data.

3.9 Protocols and End-to-End Compatibility

Telemetry should follow the CCSDS standards (See Standards Option Paper). These standards specify a CCSDS telemetry frame.

The telemetry packet shall be formatted in the host machine. An ISO/OSI layer 7 process which forms telemetry packets shall be invoked by telemetry messages. The telemetry packets will then appear as data to the network ISO/OSI layers 1-6. (See Figure 6)

At the communications gateway the ISO/OSI headers (1-6) shall be stripped off and the telemetry packets shall then be formatted into telemetry frames for transfer to the ground.

4.0 Conclusions, Recommendations & Remaining Issues

Multiple local area networks interconnected by bridges/gateways is the most suitable configuration for the Space Station onboard network. This provides a highly reconfigurable system which would potentially handle more data. The multiple networks should all conform to the same standard at IOC, but multiple standards should be allowed beyond IOC for technology insertion.

Of the systems currently defined, the ANSI X3T9.5 Fiber Data Distributed Interface (Token Ring) best satisfies the Space Station requirements for performance, reliability/fault tolerance, and standardization. This system has a high growth/technology insertion potential. The cost and risk associated with the ANSI X3T9.5 FDDI should be relatively low since this is a proposed standard.

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APPENDIX A: DECISION MATRICES

This appendix provides a set of decision matrices comparing the alternatives for configurating a local area network.

Table Al: Decision Matrix: LAN Configuration

DECISION ITEM	ALTERNATIVES (Description)	ADVANIAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
configur-ation	multiple lans	o fault tolerant o safe-haven require. o higher traffic rate o one/ module shuttle o separate core/PL o easier to reconfigure	o more complex routing	1	o more reliable o build-up o reconfigurable o security- sep. P/L & core o safe-haven requirements o handles more data
	single lan	o easy routing	o lower reliability o lower overall traffic o changes affect whole network	2	

Table A-2: Decision Matrix: LAN-Standards

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
standards	single standard for LAN	o simple bridge o commonality	o may be over-kill in some locations if lower data rates (or too small)	IOC	o simple gateway o commonality
	multiple standards for LANS	o allows technology insertion in growth o optimize LAN for local requirements	o complex gateway - flow control o requires storage at gateway	growth	o technology insertion o future req. may vary

Table A-3: Decision Matrix: LAN Topology and Media Access Methods

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
LAN topology and media access method	ANSI X3T9.5 FDDI Token Ring	o deterministic o standard o fault tolerant	o only 2 layers specified	1	o standard o fault tolerant o deterministic
	IEEE 802.4 Token Bus	o deterministic o standard	o low data rate o harder to reconfigure o more overhead o only 2 layers spec.	5	o typically low data rate o complex protocol with more overhead required to form the logical sequence
	AIPS Laning Poll Mesh	o fault tolerant o deterministic	o synchronization o longer wiring lengths	3	o long wiring lengths o not standard
	SubACS Bus with protocol similar to Laning Poll	o deterministic o highly developed o uses MIL STD parts o fault tolerant - redundant paths	o more complex NIU o oriented toward high rate periodic data o not a standard	2	o highly developed o more complex NIU o not standard
	FODS CSMA/CD/TS Bus	o efficient protocol	o more complex NIU o no priorities allowed o not a standard o experimental protocol o non-deterministic	4	o more complex NIU o not standard o no priorities allowed o non-deterministic
	Langley Mesh	o fault tolerant	o not fully defined o not a standard o possibly complex routing		o not well enough defined to evaluate
	SAE/AE-9B	o deterministic o fault tolerant o will be MIL STD	o not available yet o not fully defined		o not well enough defined to evaluate

Table A-4: Decision Matrix: LAN - Voice and Video Integration

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
voice/video data	all integrated	o less wiring	o more complex hardware o video bandwidth req. may inhibit growth		
	voice/video and sep data	o simpler hardware o allows optimization of trans. & receivers for each application	o more wiring	1	o simpler hardware o optimized network components

Table A-5: Decision Matrix: LAN-NIU Layers

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
NIU Layers	2 layers	o high performance NIU o software in host	o host must know network topology and protocol o unable to function as bridge/gateway o requires intelligent host o requires max. host CPU time & memory		o technology insertion impeded if host must know network topology and protocol
	3 layers	o functional as bridge o supports simple and intelligent hosts	o unable to function as gateway -no flow control -no multiplexing o host must know topology & protocol		"
	4 layers	o layers 5-7 application dependent o host not aware of topology & protocol o functional as gateway and bridge		1	o standardized NIU software o end to end communications connectivity fully contained in NIU o functional as bridge/gateway o transparency
	5 layers	o functional as gateway and bridge			
	6 layers	o functional as gateway and bridge			
	7 layers	o functional as gateway and bridge o off-loads host	o complex NIU	1	o maximizes standard software in NIU o minimum effort required to support heterogeneous SDPs

Table A-6: Decision Matrix: LAN-Connection Mode

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
connection mode	connection oriented	o error control o preallocates resource o smaller headers o gauranteed delivery	o more overhead	1	o Possibly for large data transfers such as text files - error control - preallocate resources
	connectionless	o less overhead o higher throughput o efficient o simpler to implement o broadcast / multicast	o no gaurantee o less error control at low level	1	o higher throughput o resources available o efficient

Table A-7: Decision Matrix: Back-End Interfaces

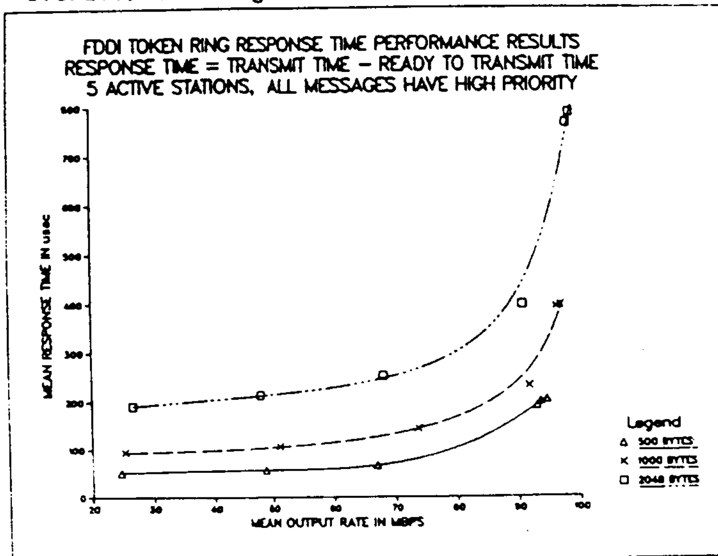
DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Back-end Interfaces	NTDS		o wire bundle o limited length		
	IEEE 488	o widely used	o wire bundle o limited length		
	MIL-STD-1553B	o widely used in avionics o one wire - serial o longer lengths		1	o widely used in avionics o one wire o longer lengths
	MIL-STD-1773	o widely used in avionics o one fiber - serial o long lengths	o harder to tap	1	
	RS232	o widely used	o wire bundle o low data rates o limited length		
	RS422		o wire bundle o limited lengths for higher rates		

APPENDIX B

LOCAL AREA NETWORK ANALYSIS

FDDI Token Ring

Performance results for the PAWS FDDI token ring simulation model are shown below. Figure B.1 represents the throughput and response time performance results for 5 active stations, generating all high priority messages. For this particular model, since all messages have top priority, message transmission is dependent only upon arrival of the token at a station - no token rotation time constraint is applied. However, only one message is transmitted for each token arrival, thus limiting each station's transmission time as well as the token rotation time around the ring to other stations. Input rates shown are mean values based on an exponential random process. The response time given is the time a message waits at the top of its source queue until it is transmitted onto the ring. The results show that for top priority, a higher throughput performance is reached with larger data fields, however, response times are also increased. Overall, the ring utilization is quite high.



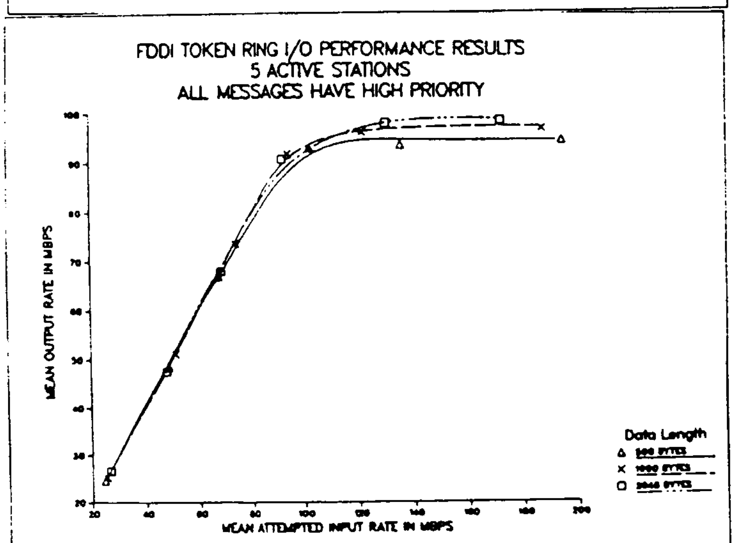


Figure B.1 PAWS FDDI Token Ring Model Performance Results - Scenario 1

Figure B.2 involves 5 active stations, all sending 3 priority levels of data with information field lengths of 1000 bytes. All priority 1 messages from one station are transmitted upon receipt of the token. Priority 2 and 3 message transmissions are dependent upon the token rotation time or the present data load. Service time is defined as a message's total queue time at a station before transmission. This shows that, for low ring traffic (under 100 Mbps total input rate), throughput and response performances are very desirable. However, as the total attempted input rate exceeds 150 Mbps, ring utilization is overtaken by all priority 1 messages.

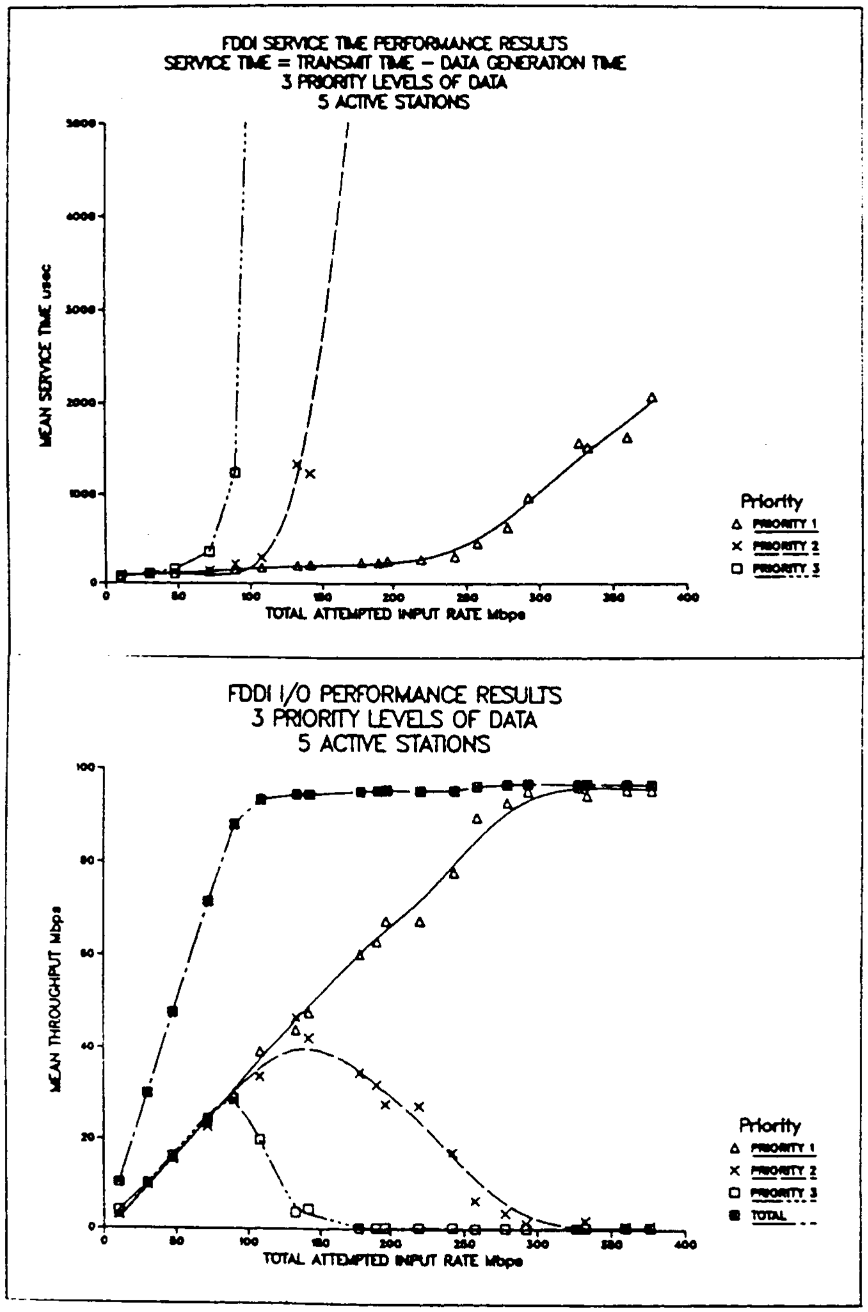
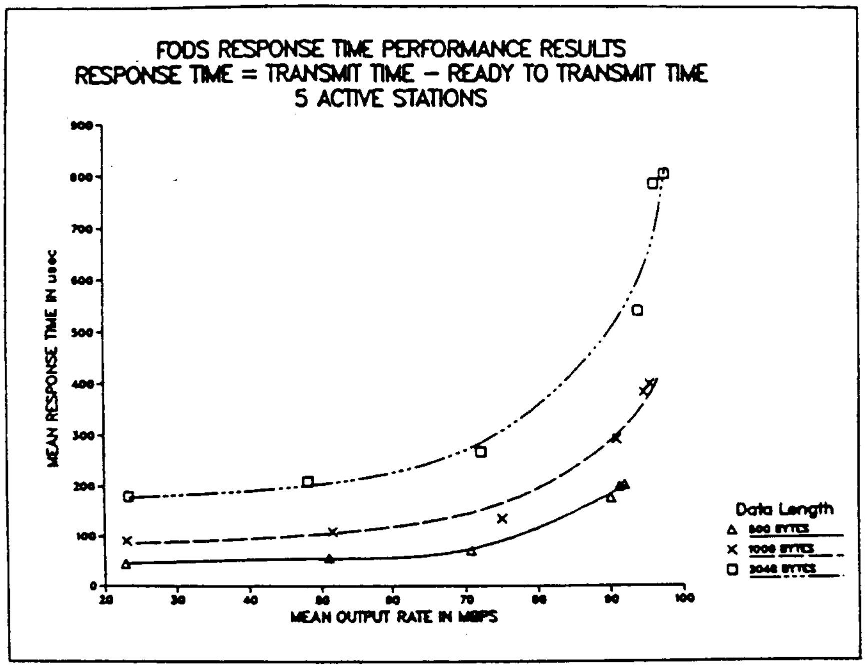


Figure B.2 PAWS FDDI Token Ring Model Performance Results - Scenario 2

Figure B.3 shows the performance results for the PAWS FODS simulation model. The model contained 5 active stations with poisson input rates and varying information lengths for messages. This shows that performance of the FODS and FDDI token ring configurations are relatively close. Again, larger data lengths receive higher throughput and response times.



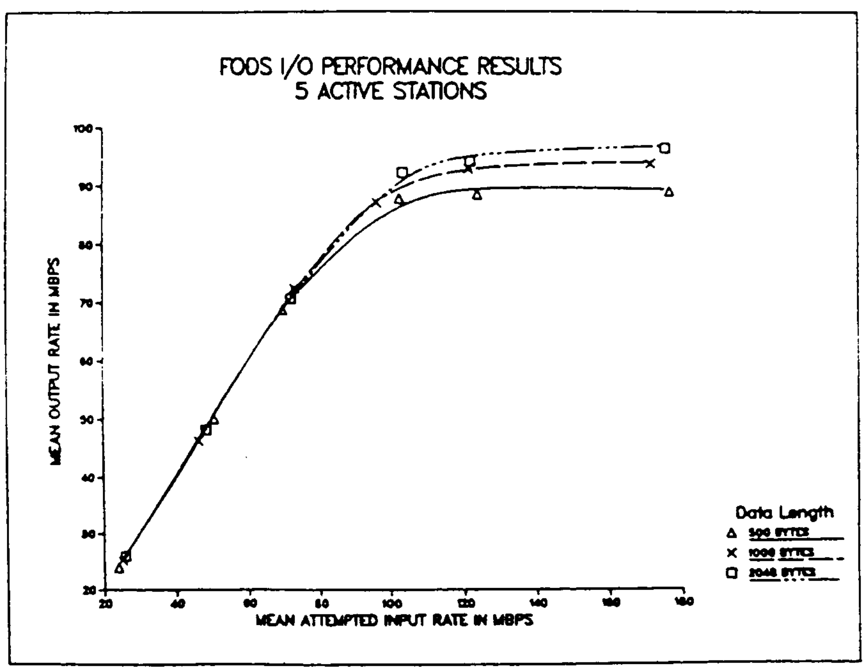
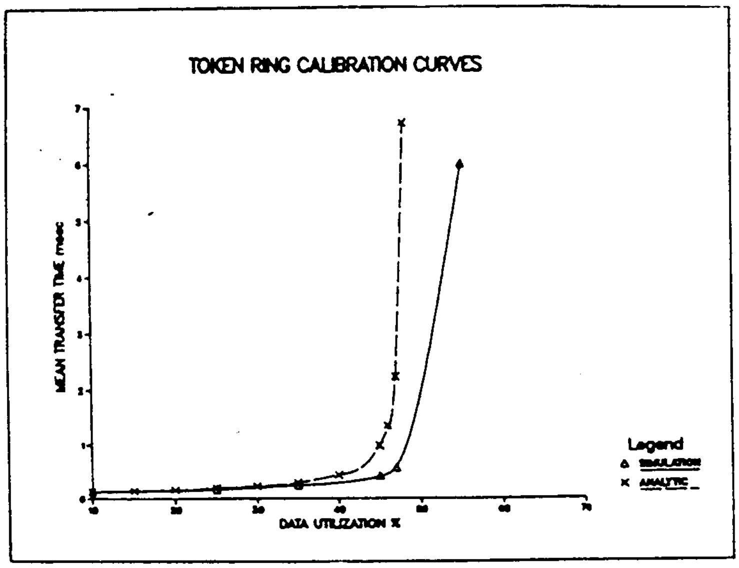


Figure B.3 PAWS FODS Model Performance Results

Token Ring

Calibration curves for the RESQ simulation model of the token ring are shown below in figure B.4. The two curves represent simulation and analytical results. The results show that ring utilization peaks at approximately 50% and transfer time is relatively low until 45% utilization where it has significant increase.

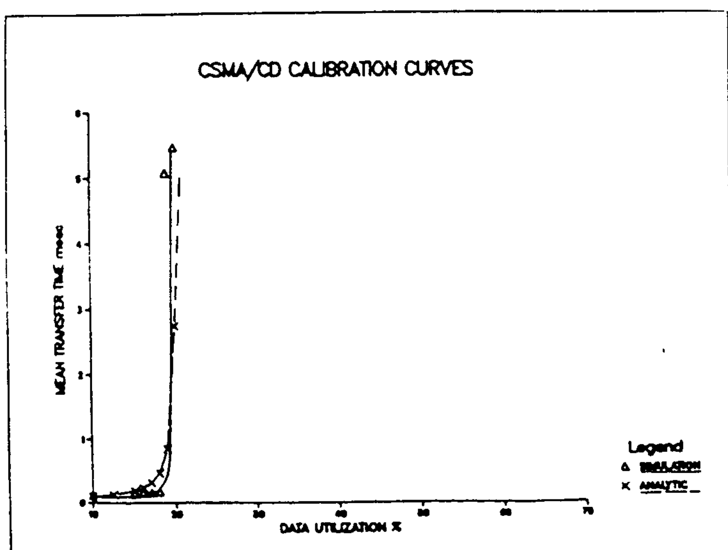


- o 46 byte data packets
- o 21 byte header
- o 3 byte token
- o 10 Mbps bandwidth
- o 12 Km total ring length
- o 5 usec/Km propogation delay
- o 1.5 bit delay per node
- o 3 byte delay per message
- o 10 nodes
- o All nodes have equal priority
- o Non-redundant configuration
- o No transmission errors

Figure B.4 RESQ Token Ring Simulation Results

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

Figure B.5, shown below, are simulation and analytical results for the RESQ CSMA/CD simulation model. The two calibration curves give a maximum utilization of only 20% and low transfer time up to approximately 18% utilization. Overall, this architecture shows poor performance.



- o 46 byte data packets
- o 38 byte overhead
- o 3.47 Km effective cable length
- o 10 Mbps bandwidth
- o 5 usec/Km propogation delay between nodes
- o 100 nodes
- o All nodes have equal priority
- o 96 byte interframe spacing
- o 168 usec delay for retry
- o Non-redundant configuration
- o No transmission errors

Figure B.5 RESQ CSMA/CD Simulation Results

VI. DISTRIBUTED OPERATING SYSTEM

DISTRIBUTED OPERATING SYSTEM TRADE STUDY

1.0 INTRODUCTION

This paper presents the results of a trade study of possible functions of the Space Station Onboard Distributed Operating System (DOS).

1.1 BACKGROUND

The Space Station DOS is responsible for the management of functions unique to a collection of devices connected together through a local area network (LAN) or by a collection of such networks. The DOS will support the autonomous operation of the onboard data management system (DMS) by providing network transparency. Operators, customers, and application processes alike (henceforth collectively referred to as "user") will be able to look upon the network of many resources as a single entity. DOS will allow users to communicate with other processes in the network through the use of a layered communications protocol. The DOS must provide these functions with high performance, user friendliness, and evolutionary growth capability, all at low costs. Any function, such as memory management or task management, normally associated with the operating system within a single processor is not addressed in this trade study.

1.2 ISSUES

This trade study is based upon the results of the task 2 (options characterization) report on distributed operating systems. As identified in that report, the issues of concern in designing an onboard DOS are:

1. The management of peripheral resources such as output devices and file systems
2. The management of memory configurations/loads in processors

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3. The mechanism by which a user accesses a remote resource, whether to obtain data or to initiate an interactive session with another process

4. The method of obtaining frequently required data

5. The network communication protocol

6. The implementation of functions associated with a network communication protocol, such as addressing, congestion control, and flow control

7. The determination of whether a given DOS function should be centralized, partially distributed, or fully distributed

8. The determination of whether a given communication protocol function should be performed in a host subsystem data processor (SDP) or in a network interface unit (NIU)

9. Additional issues include monitoring the network for performance and errors, maintaining a record of network transactions, network reconfiguration, scheduling commands and functions, and the verification of commands.

While all the above-mentioned functions are necessary components of the final system, not all are trade study issues. Issues 2, 3, 4, and 6 are considered in this report, issue 8 is addressed in the Onboard Local Area Network trade study, and file management (issue 1) is considered in the Data Management System trade study. The remaining issues will be addressed by the system definition process (Task 4).

This trade study is concerned only with individual functions and options. Any determination of whether a given function should be considered as part of the DOS or whether it should be an independent application program to be used by the DOS is left to the System Definition process.

1.3 TRADE STUDY CRITERIA

The following criteria will be used to evaluate options for each of the trade study issues:

GENERIC ISSUES (common to all trade studies)

1. Cost
   - o Development
   - o Life cycle

2. Risk
   - o Development
   - o Production
   - o Technology readiness

3. Performance
   - o CPU Utilization
   - o Memory Utilization
   - o Speed

4. Standardization/Commonality

5. Growth/Technology Insertion Potential

TRADE STUDY UNIQUE ISSUES

1. Extent of benefit to a customer

2. Extent of benefit to an operator

3. Extent of benefit to an application programmer

4. Reliability/Availability

5. Maintainability (ease of modification)

6. Effect on network traffic

1.4 APPLICABLE OPTION PAPERS:

- o 1.7.1.2. Network Interface Unit
- o 2.1.1 Data Base Management
- o 2.1.3 Distributed Operating System
- o 2.2.3 System Growth
- o 2.3 System Security/Privacy
- o 2.4 Time Management
- o 2.5.2 Local/Remote Area Communication
- o 2.5.3 Local Area Network Systems

Of the papers, 2.1.3, 1.7.1.2, and 2.5.3 are the most applicable to this trade study.

1.5 ALTERNATIVES

This section will summarize the results of the distributed operating system options paper by introducing each trade study item and options for same.

(1) Method of Accessing Remote Processes and Data

- Should there be multiple methods by which remote data or resources may be obtained?

Options:
- All remote resources and data are accessed only through interprocess communication
- Have special access schemes for frequently accessed data

- Method of Obtaining Frequently Required Data of Remote Origin
  - Applicable only if the second option is selected above

Options:
- Centralized database of commonly accessed data
- Broadcast of commonly accessed data
- Multicast of commonly accessed data

(2) Addressing

- How do applications specify the address of a process with which they wish to communicate?

Options:
- Flat Addressing (Specify only the name of the process)
- Hierarchical Addressing (address by specifying Net. [Host or Functions] Process)

- How should address tables be distributed?

Options:
- Centralized
- Fully Distributed
- Partially Distributed

- If the partially distributed option is chosen, how should unknown addresses be obtained?

Options:
- From a centralized name server
- Through broadcasting a request for the address
- Through a centralized name server, but with the ability to broadcast a request for the address as a backup

(3) Management of Memory Configuration/Loads in Processors

- What is the extent of automated reconfiguration of memory loads in processors?

Options:
- Automatic load a spare processor in the event of failure in the active processor.
- Automatically replace less critical memory loads with higher priority loads when necessary.

(4) Presentation Layer Services

- Which services are needed onboard at IOC?

Options:
- Data Encryption
- Data Compression
- Character Code Conversion
- Graphics Conversion Protocols

(5) Network Protocol Functions

(A) Packet Sizes

- Sizes of packets within the network

Options:
- Fixed Length
- Variable Length

(B) Routing

- Should routing tables be dynamically reconfigurable?

Options:
- Static Routing
- Dynamic Routing

- Distribution of Routing Tables

Options:
- Located in all NIUs
- Located at Gateways/Bridges only

(C) Congestion Control

- What is to be done to prevent or handle congestion? (congestion is the result of an NIU's buffering capacity being overrun through incoming messages from several sources)

Options:
- Buffer Allocation and Packet Discard
- Choke Packets with Packet Discard as a Backup
- Connection-Oriented Service Within the Network

(D) Flow Control

- What is the method of preventing a transmitting NIU, Host, or Process from overrunning the receiving capability of another NIU, Host, or Process?

- At Layer 2 (Flow control between individual NIUs)

Options:
- Discard Packets
- Limit Number of Transmissions Per Unit Time

- At Layer 3 (Flow control between source and destination NIUs)

Options:
- Sliding Window
- Discard Packets

- At Layer 4 (Flow control between source and destination SDPs)

Options:
- Credit Window
- Discard Packets

2.0 METHODOLOGY

This trade study incorporates the results of the Distributed Operating System, Network Interface Unit, and Local Area Network Task 2 Option Papers in determining the major issues to be resolved in defining the Space Station Onboard Distributed Operating System and the alternatives for each such issue. Additional information not covered by the Task 2 reports have been incorporated from references 1 and 2 and will be addressed in the task 4 Preliminary System Definition Report.

Each of the alternatives for a given trade study issue were carefully evaluated in order to determine their advantages and disadvantages. These advantages and disadvantages were established as a result of the team experience base at IBM in the area of operating systems, interviews with experts, and through literature surveys.

The advantages and disadvantages were then evaluated in terms of the trade study criteria in order to arrive at prioritized options for each issue. The weighting for each criteria was determined in accordance with the issue under consideration. The results of this trade study are presented below in section 3.0 and summarized as a set of decision matrices in Appendix A.

3.0 RESULTS

This section will present the results of the trade study of each of the trade study issues. For convenience, each of the issues is listed below.

1. Method of accessing remote processes and data
2. Addressing
3. Management of memory configurations/loads in processors
4. Presentation Layer Services
5. Network Protocol Functions

3.1 METHOD OF ACCESSING REMOTE PROCESSES AND DATA

Due to the need for accessing remote resources such as databases and file servers, it is accepted that some type of Request/Wait/Receive interprocess communication (IPC) facility will be required as part of the DOS. The trade issue arises when remote data is considered. Such data may be a sensor value or value of a variable, for example. For the remainder of this section, it is assumed that application programs will request data or access to a remote resource through a set of procedures provided by the DOS. The DOS in turn determines the actual method of accessing the data or resource.

If the IPC facility is used for accessing all remote objects, be they resources or data, much bandwidth will be utilized in the form of messages between requestors of data and owners of same. For data which is accessed on a frequent basis by several applications, the message traffic can comprise a significant portion of network traffic. In addition to effects on traffic, another adverse effect of IPC is the burden placed on owners of data to answer requests.

In order to overcome these disadvantages of IPC, other means of accessing frequently required data were considered. While alternatives exist which could eliminate the need for IPC between a requestor and the owner of data, such techniques have disadvantages in making the DOS more complex and being less reliable than direct IPC between the processes involved. The trade of whether or not to have an alternative means of obtaining frequently accessed data is summarized in Figure 1. The results were an alternative method of obtaining frequently required data.

ALTERNATIVES METHODS FOR DELIVERING FREQUENTLY ACCESSED DATA

As the trade study revealed, an alternative method of delivering frequently accessed data would indeed be beneficial, and alternatives in turn had to be traded. Three options were found: (1) owners of frequently accessed data

DECISION ITEM: DATA ACCESS METHOD

CRITERIA	POINTS	EXPLICIT REQUEST TO OWNER OF DATA ONLY	SOME TYPE OF AUTOMATIC DELIVERY SCHEME FOR COMMONLY ACCESSED DATA
COST - DEVELOPMENT - LIFE CYCLE	200	200 -	150 - EXTRA COMPLEXITY IF SEVERAL OPTIONS ARE TO BE AVAILABLE
RISK - MATURITY OF TECHNOLOGY - PROPER FUNCTIONING	N/A		
PERFORMANCE - CPU	200	125 - TOO MANY REQUESTS MAY SLOW DOWN OWNERS OF DATA	200 -
STANDARDIZATION/ COMMONALITY	50	50 -	40 - TWO OPTIONS, NOT A SINGLE STANDARD
GROWTH/TECHNOLOGY INSERTION POTENTIAL	N/A		
EXTENT OF BENEFIT TO CUSTOMER	N/A		
EXTENT OF BENEFIT TO OPERATOR	N/A		
EXTENT OF BENEFIT TO APPLICATION PROGRAMMER	N/A		
RELIABILITY/ AVAILABILITY	150	150 -	130 - POSSIBILITY OF LOST PACKETS DURING BROADCAST/MULTICAST
MAINTAINABILITY	100	100 -	90 - SEVERAL OPTIONS HARDER TO MAINTAIN THAN A SINGLE ONE
EFFECT ON NETWORK TRAFFIC	300	200 -	300 - COULD GREATLY REDUCE MESSAGE TRAFFIC
TOTAL AND COMMENTS	1,000	825	910 - FOR DATA WHICH IS ACCESSED FREQUENTLY BY MANY SOURCES

Figure 1. Data Access Method

transmit the values to a central database, (2) data owners of broadcast values on a periodic basis, and (3) owners of data multicast values, also on a periodic basis.

Centralized Database of Values

Of the three options, transmitting values to a database has the least promise of reducing network traffic. Instead of sending requests to the owners of data, all applications requiring a given value will have to request the database manager for the data. The only possibility of reducing message traffic arises if several values are required by each application. In that case, a single request to the database can return several values at once. The database approach does offload owners of data from the need to answer requests for the data. In addition, the cost of development of the database is not a factor since a database will exist anyway for the purpose of achiving values. In addition to a large contribution to network traffic, accessing from the database will be comparatively slower than either broadcast or multicast.

Broadcast of Values

The second option is to have owners of data broadcast values on a periodic basis. The effect of broadcast on message traffic is dependent on the configuration of the onboard LAN, the number of applications which require a particular data value and the location of these applications in terms of the configuration.

If the onboard configuration consists of a single LAN or two LANs (i.e., one for core functions and one for payload functions), a broadcast will involve only two messages at most. If multiple LANs are utilized, such as a LAN in every module, the message overhead increases. However, if many applications require a value, and further, if these applications are distributed throughout the individual LANs, the message overhead increase of broadcast is negligible.

A disadvantage of broadcast is that if a given value is required by only a small number of applications when compared with the total number of applications onboard the SS, each NIU will have to read in the message and look at the contents in order to determine if the value contained within is required by applications running in the NIU or in an attached SDP. If the number of broadcast values is large, this can result in an unacceptable amount of overhead.

One way in which this potentially serious overhead may be overcome is to indicate the contents of the message in a special header field. This approach violates the International Standards Organization (ISO) Reference Model of Open Systems Interconnection (OSI) (References 3-4) by placing information regarding the contents of the message in the Layer 2 (Data Link Layer) header. Further, such a scheme may be difficult to implement and maintain as the special field will have to be read and interpreted by the NIU interface with the physical medium.

Multicast of Values

The third scheme is multicast of values by the source. This technique eliminates the disadvantage of broadcast in that a message is specifically addressed to only those who need it. The disadvantages of multicast arise in maintaining the list of destinations and in actually indicating all the destinations in a limited length address field. The latter problem may be resolved by allowed addresses to be placed in the data field. This is particularly feasible as commonly accessed data will occupy only a few bytes of the data field, leaving much room for addresses.

The results of the trades in this area are summarized in Figure 2. It appears as if accessing data from a centralized database may be the best choice, although the bottom line scoring is close for all alternatives. However, it must be kept in mind that the trade study was performed without the benefit of actual data concerning the number of applications involved, estimated network traffic, etc. The actual choice between the options is therefore left until such data may be available.

DECISION ITEM: ACCESS METHOD FOR COMMONLY REQUESTED DATA

CRITERIA	POINTS	DATABASE OF VALUES	BROADCAST	MULTICAST
COST - DEVELOPMENT - LIFE CYCLE	100	100 - NO ADDITIONAL COST AS VALUES ARCHIVED IN DATABASE	100 - (*90 IF HEADERS CONTAIN INF. ABOUT CONTENTS*)	80 - VERIFICATION OF CHANGING DESTINATION LISTS
RISK - MATURITY OF TECHNOLOGY - PROPER FUNCTIONING	50	50 -	50 -	40 - CAN ADDRESSING SCHEME HOLD ALL NEC. ADDRESSES (*50 IF DATA FIELD HOLDS ADDRESSES*)
PERFORMANCE - CPU - MEMORY - SPEED	200	150 - TIME TO ACCESS FROM THE DATABASE	100 - ALL NIUs HAVE TO TO LOOK AT CONTS. (*200 IF CONTENTS INDICATED IN HEADER*)	175 - MEMORY FOR LISTS OF DESTINATIONS
STANDARDIZATION/ COMMONALITY	100	100 -	100 - (*50 IF CONTENTS INDICATED IN HEADER-VIOLATES ISO/OSI*)	100 - (*75 IF DATA FIELD MAY BE USED TO HOLD ADDRESSES*)
GROWTH/TECHNOLOGY INSERTION POTENTIAL	50	50 -	50 -	20 - NUMBER OF ADDRESSABLE STATIONS LIMITED (*50 IF DATA FIELD MAY HOLD ADDRESSES*)
EXTENT OF BENEFIT TO CUSTOMER	N/A			
EXTENT OF BENEFIT TO OPERATOR	N/A			
EXTENT OF BENEFIT TO APPLICATION PROGRAMMER	50	50 - DEVELOPER HAS CONTROL OVER WHEN TO ACCESS DATA - CAN GET SEVERAL VALUES AT ONCE	30 - DEVELOPER MUST CONFORM TO PERIODIC DELIVERY SCHEDULE	30 - SAME AS BROADCAST

Figure 2. Access Method for Commonly Requested Data

DECISION ITEM: ACCESS METHOD FOR COMMONLY REQUESTED DATA (CONT'D)

CRITERIA	POINTS	DATABASE OF VALUES	BROADCAST	MULTICAST
RELIABILITY/ AVAILABILITY	100	75 - DATABASE MAY NOT CONTAIN THE MOST UPDATE VALUE. DATABASE UNAVAILABLE	75 - BROADCAST MAY NOT REACH EVERYONE WHO NEEDS THE DATA	75 - SAME AS BROADCAST
MAINTAINABILITY	100	90 - MANY CHANGES NECESSARY IF DATA-BASE IS TO BE MOVED	100 - (*50 IF HEADER INDICATES CONTENTS *)	50 - MUST ENSURE ALL DELIVERY LISTS ARE UP TO DATE
EFFECT ON NETWORK TRAFFIC	250	175 - MANY REQUESTS TO THE DATABASE	225 - DATA SENT THROUGHOUT ALL THE LANs	250 - SEND ONLY TO THOSE WHO NEED THE INFORMATION
TOTAL AND COMMENTS	1,000	840	830/820 (*IF CONTENTS INDICATED IN THE HEADER *)	820/ (*835 IF DATA FIELD HOLDS ADDRESSES*)

Figure 2 (cont'd)

3.2 ADDRESSING

This category of trade study issues involves three such issues: (a) The method of addressing employed by application programs, (b) Whether address tables should be centralized, fully distributed, or partially distributed, and (c) What is the means of obtaining an unknown address if partially distributed addressing is utilized.

METHOD OF ADDRESSING BY APPLICATIONS

Two options for addressing by applications were identified. The first is flat addressing, which provides network transparency by requiring the application to specify only the logical name of the process with which it wishes to communicate or the logical name of the sensor or variable whose value is to be accessed. The second technique is hierarchical addressing, where the application specifies a logical path to the desired resource. This path may be specified by NETWORK - [HOST or FUNCTIONs] - [PROCESS, SENSOR, OR VARIABLE] where function refers to ECLS), N&C, etc. The term HOST is proved as an alternative since a given process may not be part of a well known function (e.g., payloads). In both schemes, the DOS assumes the responsibility for mapping the logical address onto a physical one.

The advantage of flat addressing is network transparency in the eye of the application programmer. The disadvantages include the need to maintain globally unique names for a large number of processes, sensors, etc. and the need for larger address tables. Hierarchical addressing makes it easier for the DOS to determine a physical address to the desired resource and eliminates the need for globally unique names. However, the network is no longer transparent to the application programmer. The results of the trade study of this issue is summarized in Figure 3. Once again, both options appear to be equally good choices.

DECISION ITEM: ADDRESSING METHOD

CRITERIA	POINTS	FLAT (NAME OF PROCESS, SENSOR, ETC.)	BY PATH NAME (e.g. NET/[HOST OR FUNCTION]/PROCESS)
COST - DEVELOPMENT - LIFE CYCLE	100	60 - COMPLEX ADDRESS TABLES - MAINTAIN UNIQUE NAMES	100 -
RISK - MATURITY OF TECHNOLOGY - PROPER FUNCTIONING	N/A		
PERFORMANCE - CPU - MEMORY - SPEED	100	90 - MEMORY	100 -
STANDARDIZATION/ COMMONALITY	N/A		
GROWTH/TECHNOLOGY INSERTION POTENTIAL	250	215 - NEED GLOBALLY UNIQUE NAMES	250 -
EXTENT OF BENEFIT TO CUSTOMER	N/A		
EXTENT OF BENEFIT TO OPERATOR	N/A		
EXTENT OF BENEFIT TO APPLICATION PROGRAMMER	300	240 - RESTRICTED CHOICE OF NAMES	225 - NEED KNOWLEDGE OF NETWORK (NON-TRANSPARENT)
RELIABILITY/ AVAILABILITY	N/A		
MAINTAINABILITY	250	250 -	175 - NEED SPECIAL SCHEME TO HANDLE CHANGES IN ADDRESSES
EFFECT ON NETWORK TRAFFIC	N/A		
TOTAL AND COMMENTS	1,000	855	850

Figure 3. Addressing Method

DISTRIBUTION OF ADDRESS TABLES

There are three options for the distribution of address tables: a centralized name server, fully distributed tables, or partially distributed tables.

A centralized name server saves memory space in individual NIUs (assuming addressing is performed in the NIUs) and makes maintenance of address tables much easier. However, performance penalties include time expended in obtaining an address and the resulting increase in network traffic as all NIUs must access addresses from this centralized location. An additional disadvantage is the cost of the SDP or NIU which is to function as the name server and the backups (for fault tolerance) of same.

A fully distributed address table means that all addresses of all sensors, variables, processes, networks, hosts, etc. are stored in every NIU. This can mean an enormous amount of overhead in terms of memory utilization. In such a scheme, address updates will be very costly in terms of the network traffic (update packets and acknowledgements), albeit such updates will not occur often. A fully distributed address table presents a great advantage access speed.

A partially distributed address table is one where each NIU maintains only those addresses which it requires. For the general case, this represents the optimal use of memory to obtain the best access speeds. However, having partially distributed address tables brings the question "What is to be done if the local table does not contain a necessary address?". The answers to this question are the options of the next issue to be resolved.

The trade study of the issue "How should address tables be distributed?" is summarized in Figure 4. The results of this trade indicate that a partially distributed address table is the best choice.

DECISION ITEM: DISTRIBUTION OF ADDRESS TABLES

CRITERIA	POINTS	CENTRALIZED	FULLY DISTRIBUTED	PARTIALLY DISTRIBUTED
COST - DEVELOPMENT - LIFE CYCLE	100	100 -	75 - VERIFICATION COST OF KEEPING TABLES UP TO DATE	75 - SAME AS FULLY DISTRIBUTED
RISK - MATURITY OF TECHNOLOGY - PROPER FUNCTIONING	75	75 -	60 - CHANCE OF UPDATES NOT REACHING EVERY NIU	60 -
PERFORMANCE - CPU - MEMORY - SPEED	300	150 - SPEED OF ACCESS	200 - MEMORY UTILIZATION	300 -
STANDARDIZATION/ COMMONALITY	50	50 -	50 -	30 - NO STANDARDIZATION OF WHICH ADDRESSES RESIDE WHERE
GROWTH/TECHNOLOGY INSERTION POTENTIAL	N/A			
EXTENT OF BENEFIT TO CUSTOMER	N/A			
EXTENT OF BENEFIT TO OPERATOR	N/A			
EXTENT OF BENEFIT TO APPLICATION PROGRAMMER	N/A			
RELIABILITY/ AVAILABILITY	75	60 - REQUIRES REDUNDANCY	75 -	75 -
MAINTAINABILITY	200	200 -	125 - EACH ADDRESS CHANGE INVOLVES UPDATES	125 - SAME AS FULLY DISTRIBUTED
EFFECT ON NETWORK TRAFFIC	200	50 - HEAVY TRAFFIC TO CENTRALIZED LOCATION	200 -	170 - OCCASIONALLY AFFECTS NETWORK TRAFFIC
TOTAL AND COMMENTS	1,000	685	785	835

Figure 4. Distribution of Address Tables

METHOD OF ACCESSING AN UNKNOWN ADDRESS

This issue is applicable only if a partially distributed approach is chosen for address tables. The alternatives for accessing unknown addresses include maintaining a centralized name server and broadcasting a request for a desired address. A third alternative is a hybrid a centralized name server scheme with the ability to broadcast as a backup.

The centralized name server has advantages of guaranteed access to the address, has potentially less traffic overhead, and is potentially faster than broadcasting for the address. Disadvantages include the cost of the name server(s), high memory usage by the name server, the need to keep the name server up to date, and the remote possibility that the name server(s) could fail.

Broadcasting a request for the address eliminates the need for an all-knowing central name server, but is potentially much slower than accessing an address from a name server. In addition, the formerly mentioned problems of burden on every NIU to read the message and the message traffic associated with a broadcast apply. In addition, since broadcasts are generally not acknowledged, there is no guarantee that the NIU which knows the requested address ever receives the request or that any reply will reach the requestor.

The hybrid approach is: (1) first attempt to access from a centralized name server, and if it is not available, (2) then a broadcast request for the address may be sent. The results of the trade study are shown in Figure 5. For this issue, a centralized name server or a centralized name server with broadcast as a backup technique seems appropriate. The former will be cheaper to develop, while the latter provides more fault tolerance.

3.3 MANAGEMENT OF MEMORY CONFIGURATION LOADS IN PROCESSORS

This topic was not addressed in the options study. An extended discussion of the issues is therefore provided.

DECISION ITEM: ACCESSING UNKNOWN ADDRESSES (IF PARTIALLY DISTRIBUTED ADDRESS TABLES)

CRITERIA	POINTS	CENTRALIZED NAME SERVER	BROADCAST REQUEST FOR ADDRESS	CENTRAL NAME SERVER WITH BROADCAST AS BACKUP
COST - DEVELOPMENT - LIFE CYCLE	50	30 - COST OF NAME SERVER SDPs	50 -	20 - ADDED DEVELOPMENT COST
RISK - MATURITY OF TECHNOLOGY - PROPER FUNCTIONING	N/A			
PERFORMANCE - CPU - MEMORY - SPEED	300	250 - HIGH MEMORY USAGE	200 - SLOW ACCESS	250 - HIGH MEMORY USAGE
STANDARDIZATION/ COMMONALITY	N/A			
GROWTH/TECHNOLOGY INSPECTION POTENTIAL	N/A			
EXTENT OF BENEFIT TO CUSTOMER	N/A			
EXTENT OF BENEFIT TO OPERATOR	N/A			
EXTENT OF BENEFIT TO APPLICATION PROGRAMMER	N/A			
RELIABILITY/ AVAILABILITY	300	275 - NAME SERVER MAY BECOME UNAVAILABLE	250 - NO GUARANTEE OF OBTAINING ADDRESS	300 - BACKUP IF NAME SERVER UNAVAIL.
MAINTAINABILITY	50	30 - NEED TO KEEP NAME SERVER UP TO DATE	50 -	30 -
EFFECT ON NETWORK TRAFFIC	300	275 - SLIGHT EFFECT ON TRAFFIC	225 - BROADCASTS TRAVEL THROUGHOUT SS	260 - WORST CASE BAD AS BROADCAST
TOTAL AND COMMENTS	1,000	860	775	860

Figure 5. Accessing Unknown Addresses

The management of the configuration of application tasks both within a single processor and among the resources of the network is a problem which presents several opportunities for automation. From the time that application tasks are initially loaded into the processors of the network, failures, maintenance, and even entering different phases of Space Station operation may require reconfiguration of tasks among resources. The most critical need for an automated reconfiguration facility is in managing redundant computers. Failures in computers running time-critical applications require that the switch to a backup be automatic as the applications running in the computer may not withstand the delay associated with crew or ground controlled reconfiguration.

Other situations requiring reconfiguration involve the loading of software either into idle spare machines or into machines in which applications already reside. Such situations may arise as a result of failures in processors with no backups or just in the course of time. An example of the later is the use of maintenance expert system by a crew member. Since expert systems are expensive in their use of resources, it is conceivable better to load the expert system software into a processor only when it is to be used. The decision of where to load the software may be made by the crew member or by the DOS. It is important to note that any reconfiguration of applications among processors is meaningful only if the applications have access to necessary sensors and effectors.

Assuming that the Space Station architecture allocates a pool of processors as spares, it appears feasible that the DOS be capable of assigning and loading software from mass memory into such a spare processor as necessary. problems arise when all available resources are being utilized.

One architectural option is to have fixed memory configurations. The configurations will allocate certain locations in memory for DOS and other system software. The remaining locations in memory will be used by application tasks. Since all processors will contain certain systems software, the term memory configuration will henceforth refer to groups of applications tasks to be loaded into a processor at once, with no possibility of dividing individual tasks among different processors. Such configurations may be amended by an overlay, where a second set of application software (second configuration) replaces the already resident configuration. If a new configuration must be loaded into a processor, a full replacement of preloaded application tasks is necessary. The task of deciding which configuration is more important in a given situation may be automated by use of an expert system or by other means such as priority tables.

The second architectural option is to allow tasks to be dynamically loaded into processors. This option provides a better solution to the problem of fault tolerance (e.g., more flexible) and also has the potential for making better use of available resources than the fixed memory configuration scheme. With this option, if all processors are being utilized and there is a need to load a new task, then a decision must be to either to (a) find a processor which is capable of assimilating the new task without adversely affecting already resident software, or (b) to partially or fully replace the resident software. These schemes require an algorithm to determine where a task may be moved to, the ability to assign a priority to that task in its new environment, and a dynamic linking capability. A dynamic task transfer capability will make verification more difficult since the possible combination of tasks within a processor will not be predictable. The final drawback of task migration is the potential inability to meet timing and jitter requirements due to interference between tasks.

In summary, the results of this trade indicate that the management of the configuration of application tasks amont network processors will be partially automated. Certainly, the need to automatically switch to backup computers is a necessity since time critical functions may be involved. The choice of a spare computer into which new software is to be loaded is also recommended for automatation. The only decision left open is the case when all processors are being utilized and new software must be loaded. The extent of automation is dependant on the architecture which is chosen. The results of this trade study will be combined with that of potential architectures to determine this extent of automation. Currently, it appears that the fixed memory configuration scheme will be the choice of architecture. If this choice holds, it would mean that an automated decision making capability could be used to reconfigure the loading processors even when all processors are being utilized. Of course, a crew or ground override capability must be implemented to allow manual control in situations where it may be necessary.

3.4 PRESENTATION LAYER FUNCTIONS

The purpose of this trade is to assess which Presentation Layer (6) functions (if any) will be required onboard the Space Station at IOC. The functions under question include (1) data encryption, (2) data compression, (3) character code conversion, and (4) graphics conversion protocols.

The potential need for the functions listed above is based on the requirements stated in the Space Station Request for Proposal (RFP) (Reference 5). It is indicated that data encryption is to be provided by the DMS (Paragraph C-3 3.1-D). Further, the need to handle very large amounts of data suggest that data compression could be very useful at IOC.

The need for functions 3 and 4 is not clear. The RFP (Paragraphs 2.1.5 and 2.2.5.3-G) indicates that common hardware and software will be employed as much as possible. Functions 3 and 4 are used explicitly for converting between non-standard formats. For this reason, functions 3 and 4 have been chosen as growth items, assuming that the requirements for commonality are relaxed in time. There may be a need, however, to translate between possibly incompatible formats employed in onboard and ground systems. For these situations, it would be much more cost effective to perform such conversions on the ground. The results of this study are summarized by the fifth decision matrix in the appendix section.

3.5 NETWORK PROTOCOL FUNCTIONS

The final area of trade study issues falls under the classification of network protocol functions. These issues, packet sizes, routing, congestion control, and flow control, are part of every network protocol implementation. Another network protocol function, addressing, has been discussed separately. Unlike the other trade study issues, it is difficult to perform studies on functions such as routing, congestion control, and flow control without knowledge of network traffic conditions and the needs of the application programs. For this reason, an attempt will not be made to select a single implementation technique for each function, but rather, suggestions will be made as to which of the options may be appropriate.

PACKET SIZES

The issue related to packet sizes is whether to have fixed length or variable length packets in the network. Fixed length packets make development and maintenance easier, but may waste bandwidth and be unfair. If the fixed length is too high, small messages such as sensor values will waste most of the packet bandwidth. If the packet length is chosen to be too small, then long messages, such as file transfers, will have to be broken into many packets, resulting in longer delivery times as packets wait to get media access. Variable length packets make better use of available bandwidth and can be more fair.

However, having variable length packets will make initial development costs higher. For reasons of growth capability and better utilization of bandwidth, variable length packets are suggested.

The maximum packet size will be determined once more is known about the overall network traffic. At present a preliminary value of 2048 Bytes has been chosen.

ROUTING

Once a destination address is determined, it is up to the routing function to determine the physical path which should be taken in order to eventually reach the destination. In a single ring or bus configured LAN, an address specifying "NIU_HOST_PROCESS" is sufficient for reaching the final destination as the NIU for which the packet is addressed simply picks it up. However, when a packet is addressed to a destination in another network, (e.g., NET_NIU_HOST_PROCESS), a routing table must be consulted in order to determine the path to reach the destination network. The trade issues associated with routing include (a) static vs. dynamic routing tables (reference 4) and (b) the distribution of routing tables.

Static routing tables are those which are determined and loaded into the appropriate NIUs or SDPs before the network is activated. Such a table does not change thereafter until an alternative routing table is once again explicitly loaded (e.g. when reconfiguration occurs). These tables have the advantage of simplicity and can provide good performance. In addition, it is possible to construct static routing tables in such a way that alternative routes can still be utilized. However, static routing tables are not adaptable with respect to changing network traffic conditions and configuration.

Dynamic routing tables have the advantage of being adaptive, but require a more complex DOS and may also cause an increase in network message traffic. Routing tables may be reconfigured locally or by centralized server. Numerous schemes exist by which dynamic routing algorithms may be implemented.

Based on the probable ring or bus-connected LAN configuration of Space Station, the need for routing will be very limited (i.e., routing tables are necessary only for determining paths between networks). Since the number of such networks will be small and will not change often, a static routing table will be sufficient for the needs of SS.

Distribution of Routing Tables

This issue is the placement of the static tables within the Space Station network of individual LANs. Since routing is necessary to determine the path from one network to another, routing tables should be maintained in every bridge. The remaining question is whether or not routing tables need to be maintained in every NIU.

Consider a LAN with only one bridge. In such a LAN, if an NIU encounters a need to transmit a packet to another network, it may simply forward the message to the bridge, which then looks up the route to the final destination and forwards the packet. In a LAN with more than one bridge, a particular bridge may be designated to forward all inter-network messages. The other alternative is maintain a routing table in each NIU, so that the load in the bridges is more evenly distributed.

Since the size of the routing table will be small, placing the routing table in every NIU will not be extremely wasteful of memory. For this reason, the choice of whether to place routing tables in every NIU of a LAN with multiple bridges is left as a design decision.

CONGESTION CONTROL

Congestion is the result of a given NIU's buffer space being overrun by incoming transmissions from several sources. Various schemes exist for implementing congestion control (reference 4) including (a) allocating buffers to incoming packets by the packet's priority, number of hops traversed by the packet (seniority), or an a FIFO basis and then simply dropping packets as buffer space is exhausted, (b) by monitoring the traffic on incoming lines and as congestion appears likely, sending a message to the sources of the packets requesting a reduction in the number of packets being transmitted, and (c) by using connection-oriented service within the network, which prevents congestion by preallocating buffer space for each message.

The trade in this area is based on the assumption that congestion will occur infrequently due to the careful design of the network (i.e. sufficient network bandwidth, etc.). With that assumption, connection-oriented service (at Layer 4) is suggested for long messages (such as file transfers) while the buffer discard algorithm may be sufficient for small messages. Note that the latter scheme requires that end-to-end acknowledgements be utilized. Otherwise, there is no guarantee that a given packet reaches its destination. The choke packet scheme will be useful if congestion is likely to occur frequently and in general, messages are sufficiently long that the source may be requested to 'choke' its transmissions. Since congestion and long messages are not likely to be frequent occurrences onboard the Space Station, the choke packet scheme is not recommended.

FLOW CONTROL

Flow control is prevention of a faster NIU, host, or process from overrunning a destination NIU, host, or process. With this definition, flow control is a part of Layers 2-4 and the Layer 5/Layer 4 interface of the ISO/OSI reference model. This section presents options for flow control at each layer as obtained from reference 6. Once again, more concrete figures for expected traffic and better knowledge of the needs of the application processes will be required before effective trades can be performed. As in previous sections, suggestions will be made regarding the option(s) most appropriate for SS.

Flow control at layer 2 is concerned with transmissions between NIUs. With the requirements for commonality onboard SS, flow control at layer 2 should not be necessary as a NIU will likely have matched speeds for sending and receiving. However, if in growth, flow control becomes necessary, the options are a discard packet algorithm (flow control at the destination) or to limit the number of packets which may be transmitted per unit of time (flow control at the source). If the former is employed in a ring network, very fast feedback can be provided to the sender by simply modifying a bit in the packet if it cannot be accepted. Limiting the number of transmissions out of an NIU may be helpful in controlling jammed NIUs, but it may be difficult to choose the optimal limit to provide flow control and yet not unduly restrict the sending NIU. For these reasons, the discard packet scheme is recommended instead of the transmission limit scheme.

Source-Destination flow control is achieved at Layer 3. At this level, several techniques of flow control exist. These include among others: (a) the sliding window scheme and (b) the discard packet scheme. The sliding window scheme is one way of implementing connection service at Layer 3.

The sliding window scheme requires a small number of buffers to be allocated at the destination NIU, but is an effective means of flow control and sequencing. This scheme may be used in conjunction with connection service and is recommended for long messages and critical messages.

Discarding packets is easy to implement, but at layer 3, may be considered to be too wasteful of bandwidth since a packet may have travelled through several networks in order to reach the destination. This scheme also implies that the packet must be acknowledged, otherwise there is no guarantee of delivery. The discard packet algorithm will be sufficient for messages using connectionless service.

Flow control at the transport layer (layer 4) may be implemented by at least two techniques. One method is the credit window scheme, where before transmission begins, the destination host is contacted and queried as to the number of packets which may be accepted. This method may be utilized in conjunction with connection-oriented service at the transport layer. Another technique, to simply drop packets, may be employed for messages using connectionless service.

4.0 CONCLUSIONS, RECOMMENDATIONS & REMAINING ISSUES

This trade study has addressed several pertinant issues regarding the development of a Space Station Distributed Operating System (DOS). The study has resulted in the following recommendations:

Data Access Method - Primarily through interprocess communication (IPC), with commonly acquired data being accessed through a centralized database, or obtained through broadcast or multicast.

Addressing	–	Choice of flat vs. heirarchical addressing left as a design decision. Address tables should be partially distributed, with unknown addresses being accessed primarily through a centralized name server and through broadcasting a request for the address if the name server is unavailable.
Management of Memory Configuration/Loads in Processors	–	Automatic switching to backups, automated loading of spare processors. Automated replacement of lower priority loads with higher priority loads is a possibility if fixed memory configurations are utilized.
Presentation Layer Services	–	Data encryption and data compression should be made available if necessary. Other presentation layer services are null at IOC and may be added as onboard commonality decreases.
Network Protocol Functions	–	Variable length packet sizes with max size = 2048 Bytes
	–	Static routing tables – Decision of whether routing tables should exist in every NIU or only in bridges is left as a design issue.
	–	Congestion control through connection service for lengthy, critical, and high-priority messages. Congestion control for other messages through packet discarding.
	–	Flow control at layer 2 through dropping packets
	–	Flow control at layer 3 through dropping packets for connectionless service
	–	Flow control at layer 4 through credit window protocols for connection-oriented service, through dropping packets for connectionless service

A number of issues remain to be addressed in the preliminary system definition report. Both the Distributed Operating System options paper and trade study have not dealt with the question of determining which functions should be considered as part of the operating system and which should be considered as applications to be invoked by the operating system. In addition, the system definition report should address the question of division of labor between SDPs and NIUs and any interfaces between the two. Finally, the system definition report should present an integrated system composed of the many individual functions which have been discussed in the context of this trade study and the options paper.

5.0 REFERENCES

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6.0 APPENDIX

This appendix contains a summary of the results of the trade study in the form of decision matrices. The matrices list the item under consideration, options for the item, advantages and disadvantages for each option, choice(s) among the options, and rationale for the choice(s).

System Definition Decision Matrix: Distributed Operating System (Page 1 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
method of information access	1 send explicit requests to the owner of desired informatn	o guaranteed delivery through use of hand-shaking o flexible - obtain data when desired	o potentially high levl of network traffic o owners of data have to answer many reqsts	IOC	o guaranteed access o useful for critical data and infrequently accessed data
	2 periodic delivery of commonly accessed data without explicit requests	o easy access to data o smaller address tabls o more transparent o potential reduction in message traffic o offload owner of data from answerng rquests	o shared network re-sources limited to data o less reliable o less privacy/security o could increase network traffic	IOC	o useful for data which is frequently accessed by many processes due to ease of access and reduced message traffic in the network
automatic delivery of data on a periodic basis	1 database of values	o allows concurrent access of many values o offloads SDPs from the task of answering requests for data	o high network traffic o reliability - both of the database and is data up-to-date? o cost of SDP to perfrm as the database o data access time	2rd choice	o high network traffic o cost of SDP o reliability o will be useful if many appli-cation require frequent access to many values
	2 broadcast data values	o processes need not send requests for data o ease of access	o broadcast is less reliable than a database approach o every NIU has to look at message content	1st choice	o If header contains information regarding contents, each NIU need not read in the messge and explicitly look at the contents. However placing information about message content in a layer 2 header is a violation of ISO/OSI stnd
	3 multicast	o least traffic of all o best performance - fast access - only those NIUs which need the data have to look at the data	o need to maintain delivery lists o possible limit on number of stations which may be addressd	1st choice	o Multicast is useful only if all the stations which need the data can be specified in the address field. A trick is to use portions of the data field for addressing informatn. This then also becomes non-standard. The choice between broadcast and multicast is dependent in needs of the applications.

System Definition Decision Matrix: Distributed Operating System (Page 2 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
centralized vs. distributed by item (see list below)	1 centralized	o less memory use in individual NIUs o better control	o time wasted in information access o requires redundancy		
	2 fully distributed	o ease of access o speed of access	o replicated software o replicated tables		
	3 partially distributed	o optimize ease of access vs. memory	o can middle ground please everyone?		
User Interface				3	o avoid replicated software o distribution for ease of access
Processor Management				2,3	3 at user interface if no dynamic transfer of processes 2 if dynamic transfer of proceses
File, I/O Management				1	o centralize at file servers/ I/O devices
Address Tables					
- Sensors/ effectrs				3	o For all address tables, store frequently accessed addresses locally to greatly improve access times
- Perphrls				3	
- Selected variabls & data				3 3	
- Active pro- cesses				3	
Routing tables - connections between networks				2	o Maintain a copy of routing table at every NIU since number of networks is small or at bridges/gateways only

System Definition Decision Matrix: Distributed Operating System (Page 3 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Accessing unknown addresses -if address tables are partially distri- buted	1 centralized table of addresses of all SS resources	o Assured of obtaining address if resource exists. o faster than 2	o storage overhead o may occationally be unavailable o cost of SDP to act as name server	IOC 2nd choice	o necessary table space for a centralized table will not be prohibitively large o less cost than hybrid
	2 no central table(s) broadcast message asking for address of desired resource	o avoid central storage overhead	o can be very slow, especially to realize resource doesnt exist o no guarantee of ob- taining an address	no	o can be too slow to meet SS requirements o less reliable than central table since broadcast is not acknowledged by everyone (i.e., sender does not know if owner of resource got the request for address)
	3 hybrid - central with broadcast as a backup technique	o same as 1, but better reliability due to 2 as a backup technique	o storage overhead o slightly more complex than other schemes	IOC 1st choice	o provides backup ability if centralized table is unavailable without much increase in cost
Addressing by the application Process	1 Flat addressing (by name of process, sensor, data item)	o network configuration fully transparent to application process	o requires larger address tables o requires use of globally unique names	either	o goal is to provide transparency o compromise by requiring user to specify that a packet is for a ground destination
	2 Hierarchical addressing -specify path name: net/(host or functn)/ process	o smaller address tabls o less complex operatng system	o lack of resource transparency o difficult to maintain if addresses change	either	o lack of total transparency o maintenance o globally unique names are not necessary

System Definition Decision Matrix: Distributed Operating System (Page 4 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Reconfiguration of loads in processors	1 Automated switching to backups in the event of failures	o much faster than with human involvement. o necessary for time-critical computers running time-critical applications	o cost of development and verification	IOC	o necessary to meet SS requirements
	2 automatically load a "spare" processor if the architure allows for spares	o reduced need for human intervention, appears to be within capabilities of current technology	o Cost of development and verification	IOC or growth	o Exact costs of development still need to be determined
	3 automatically replace less critical applications w/ ones of higher priority	o least needs for human intervention	o Cost of development and verification o Automated decisions of what to replace may be non-ideal	IOC or growth	o Results depend on the architecture that is chosen o Further analysis needed to determine true cost
Privacy/ Security	o Restrict access to secure processors/ payloads	o useful customer service	o need mechanism to check permits	IOC	o Basic requirement
	o Data encryption services	o "	o utilize resources	IOC	o basic requirement

System Definition Decision Matrix: Distributed Operating System (Page 5 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Presentatn layer services	o Data encryption	o useful customer service	o utilize resources	IOC	o RFP requirement
	o Data compression	"	"	IOC	o If need exists
	o Character code conversion	"	"	growth	o cheaper if provided by ground half of gateway for conversions between ground-based and SS-based systems. Not needed onboard as long as terminal, graphics packages, etc. remain standarized
	o Graphics converion protocol	"	"	growth	
Routing	1 Static Routing	o simple to implement o can still use alternative routes o good performance	o nonadaptive o configuration and traffic should be stable	IOC	o routing necessary for only internetwork traffic o number of LANs in configur. will be relatively stable
	2 Dynamic Routing	o adaptive	o more complex o	growth	o complexity does not match benefit
	a) - Centralized	o generates optimal routes o reduces workload of individual NIUs	o requires redundancy o high concentration of traffic around the centralized router		
	b) - Distributed	o routing traffic evenly dispersed o better reliability	o most traffic of all the schemes		
Packet size	1 Fixed length packets	o simpler network protocols	o could waste bandwidth	no	o wastes bandwidth
	2 Variable length packets	o good use of bandwidth	o requires more complex protocol	IOC	o trade complexity for flexibility

System Definition Decision Matrix: Distributed Operating System (Page 6 of 6)

DECISION ITEM	ALTERNATIVES (Description)	ADVANTAGES	DISADVANTAGES	CHOICE	DECISION RATIONALE
Congestion control (NIU/gtway overrun by several sources)	1 buffer allocation & discard packets - by priority - by FIFO - by source - ground vs local	o simple to implement o prevents network congestion	o Need for storage at source and use of acknowledgements o Wastes bandwidth	1st	o chance of congestion is small o useful for small messages o small, but critical messages saved from discard by priority
	2 choke packets to sources involved	o conserves bandwidth o invoked dynamically	o reliability - choke packet can be lost	2nd	o useful if congestion occurs frequently
	3 connection-oriented service in the netwrk	o prevents network congestion	o waste of time and re-sources for small msg	1st	o use connection service for long messages (file xfer, etc.)
Flow Cntrl NIU-NIU (layer 2)	o discard packets	o reduce wasted trans-missions with well-chosen allocation method o easy to implement	o deciding how to allocate buffers	IOC	o well suited for token ring since source is notified immediately regarding whether a packet was accepted or dropped
	o limit number of packets which may be transmitted by an NIU during a given period of time	o easy to implement o limits transmission by a "jammed" NIU	o limit small--restrict NIU ; if large -- not effective flow contrl o need to count packets leaving an NIU	2nd choice	o handles runaway NIU, but requires count of messages. o may not provide good flow control if packet per unit time limit is too large
Between Src.-Dest. (Layer 3)	- sliding window	o also takes care of sequencing	o allocated buffers for windows	IOC	o method of implementing connection service, useful for long messages
	- discard packets	o fast and easy	o wasted bandwidth from dropped packets o need storage @ src & acks, else lose pckts	IOC	o useful for small messages o critical messages protected by priority from being dropped
Between Transport Connections	- credit window	o guaranteed acceptance	o time spent in getting credit (permission)	IOC	o useful for long messages and critical messages
(Layer 4)	- discard packets	o fast and easy	o wasted bandwidth from dropped packet o need storage @ src & acks, else lose pckts	IOC	o useful for small messages and non-critical messages

VII. SOFTWARE CONFIGURATION MANAGEMENT

SOFTWARE CONFIGURATION MANAGEMENT TRADE STUDY

1.0 INTRODUCTION

1.1 BACKGROUND

Configuration Management is the identification of the characteristics of a computer software system at discrete points in time for purposes of controlling changes and maintaining the integrity and traceability of the system throughout its life cycle. Configuration Management (CM) is important to the Space Station because it will be the mechanism for NASA to authorize capabilities, track progress and ensure that the software deliveries are cohesive. A CM system which provides the functions listed below can also be considered a tool used by subsystem and customer management to plan, schedule and track the tasks and resources assigned to them.

There will be a large number of areas using the SSE, including application software developers, SSE developers, payload developers, ground support developers, and various test functions. In this study, the term "user group" will be used to define some set of users which is working on the same task and requires the same functions from the SSE.

The Configuration Management system should encompass the following:

DEFINITION OF INCREMENTAL SOFTWARE RELEASES AND CAPABILITIES. The capability to define software increments will be required since the Space Station itself will be built incrementally, and there will be periodic upgrades in technology and function. A way to define and record capabilities (e.g., CRs–Change Requests) will also be required together with a method of associating the capabilities with projected releases.

CONTROL OF CAPABILITIES. The CM system must allow the user group to define the approval level required for updates. This will vary between user groups depending on the autonomy level of the subsystems involved. For example, one subsystem may require multiple control board approval, while a completely autonomous payload system would require no approval or internal approval only.

COSTING CAPABILITIES. The CM system must provide a way to associate a cost with each requested update. This cost could affect the approval of the update and the assignment of the update to a release.

TRACKING MECHANISM. The Configuration Management system must allow for defining a consistent set of development milestones and recording of projected schedules and actual progress according to those milestones. The capability to generate reports and graphical representations of this data must also be provided.

DEPENDENCY IDENTIFICATION. The system must provide a way to record dependencies among projected capabilities.

COMMUNICATION. A subset of the data maintained by the Configuration Management system will be of interest project wide and must be made available. Other parts will remain strictly for the use of the subsystem developers and their NASA monitors.

TMIS INTERFACE. The interface between the TMIS and the SSE Configuration Management functions must be defined in such a way as to minimize redundant data and to provide cross referencing capabilities.

It is assumed that to maintain configuration control over the Space Station software, the project will utilize a series of NASA, contractor and customer control boards (similar to what has been used in previous NASA projects) and an automated data base system for storing and enforcing decisions made by the boards. Figure 1 is an example of how the boards may be structured. The boards are responsible for defining both the software increments and their contents. They must ensure that the scheduled contents of each increment meet the requirements defined for the increment. Lastly, through authorized board representatives, they are responsible for entering their decisions into the data base.

This trade study addresses three approaches to providing the data base system mentioned above. Since the board structure is currently undefined and may change after it is initially established, the impacts of such modifications on each alternative will have to be considered.

Some assumptions were required to be made prior to beginning this trade study. They include:

- o There will be a large number of areas using the SSE, including application software development, SSE development, ground support development and various test functions. The SSE will also be made available for payload application development. We will use the term 'user group' to define some set of users working on the same task. It is assumed that each of the four primary Space Station sites may contain multiple user groups and that user groups may exist at other locations as well. Because of this assumption, this trade study will be totally independent of the trade study being performed on the facilities options.

- o The basic element of configuration control will be called a 'control instrument'. This generic classification would cover things such as Change Request (CR), Discrepancy Report (DR), Program Change Request (PCR), Problem Trouble Report (PTR) and any other type of document which might result in a software change.

1.2 ISSUES

There are a number of issues in the area of configuration control. Some of the issues are:

1) The configuration control board structure across the project and how much uniqueness will be allowed at each site and within each user group.
2) Whether the payload customers will be encouraged or required to use the SSE for their development. NASA may want to make the SSE available for use by all customers and would want to maintain configuration control over non-autonomous payload software. If this is the case, the easiest way to accomplish this would be to require the non-autonomous software to be developed in the SSE under its CM system. If the SSE is perceived by potential customers are being counter-productive, it could discourage them.
3) The level of security (privacy) required among user groups on detailed planning and scheduling data.

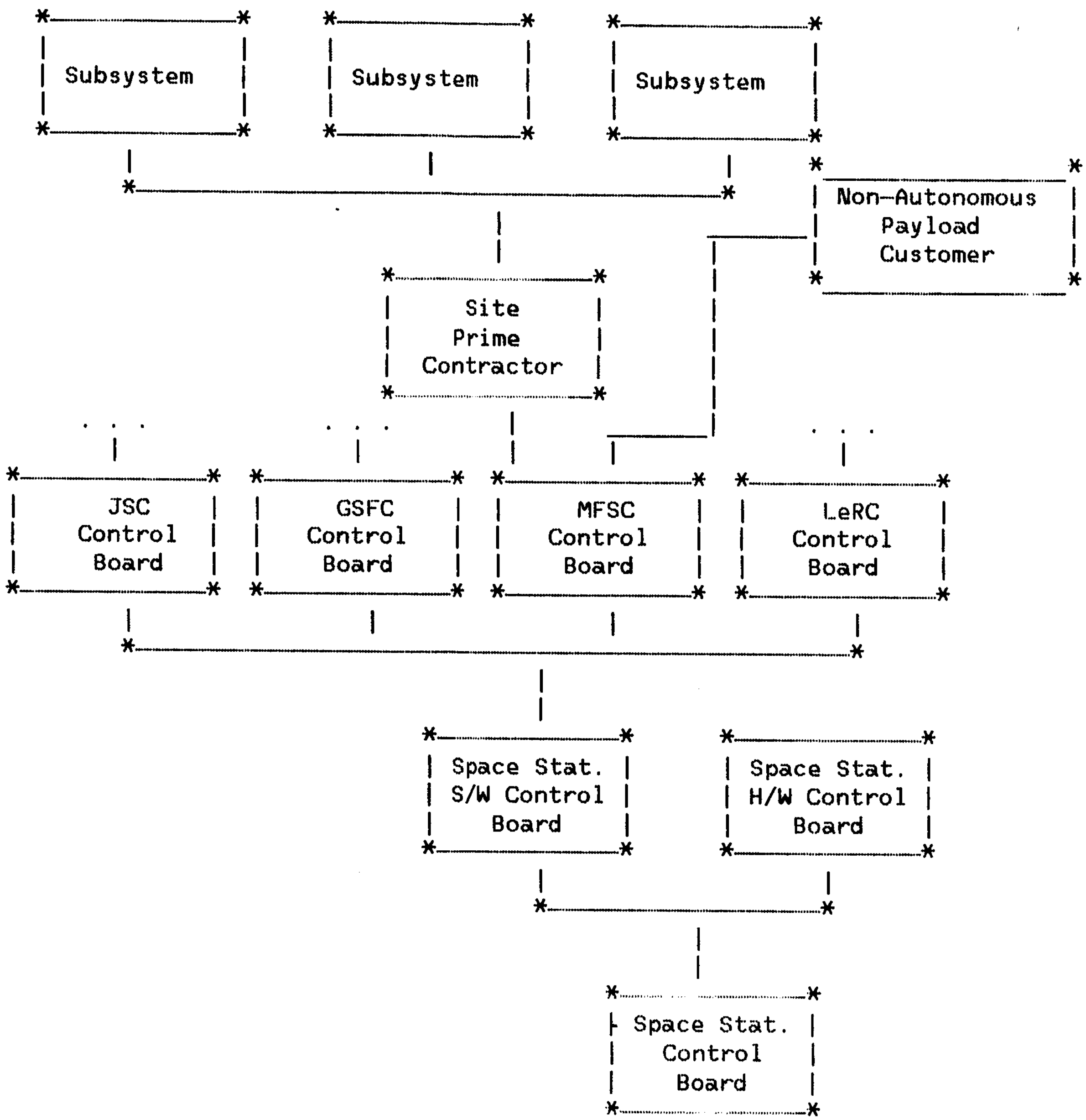

Figure 1. Proposed Space Station Control Board Structure

4) Software components managed. Traditionally, requirements, design and source and executable code have been configuration controlled. The Space Station must address these plus elements of new technologies such as new DBMS.

5) TMIS interface.

1.3 TRADE STUDY CRITERIA

Several criteria have been selected to be used in the evaluation and comparison of the selected Configuration Management alternatives. The criteria and a short description of each may be found in the following sections.

1.3.1 GENERIC

COST

This criterion addresses the basic costs for the initial development or acquisition of the CM system and for maintaining and operating it for the duration of the project. This cost will be only that amount necessary to implement the functions described in "Background". Since most of the other criteria address attributes of the CM system which can be improved if enough money is invested, this basic cost comparison will not include any cost to make the CM system easier to use, more adaptable, etc. The cost of these enhancements will be considered along with the criteria which are affected.

DEVELOPMENT TIME

The intent here is to consider factors other than available manpower (or money) which may affect the amount of time required to implement the CM system. An example may be the amount of time necessary to define a system's design because of its complexity. Having more manpower available in this case may not decrease the total amount of time required. Under this criterion, commercially available systems will be given favorable scores if their purchase prices are less than development cost.

TECHNICAL RISK

This will look at each CM system alternative and determine what attributes of the alternative might influence the chances of successfully implementing that CM system. Items considered will include the complexity of the required components and the current state of the technology required to build the system.

IMPACT ON OTHER TOOLS

This deals with how other tools (part of the SSE or site-specific) are affected by the structure of the CM database. Items considered will include ease of extracting data and effect on tools of changes to the database (especially if a change to the database can affect a site's tools even though the change does not directly affect the site). The impact of Configuration Management changes on the interface between the SSE and TMIS will also be considered here.

MANAGEABILITY OF DATA

This will assess whether a particular alternative will allow tracking (and enforcement) of the way the data is used at different sites. The aim here is to allow users from different sites to be confident that a piece of data is used consistently at each site.

EASE OF USE

This will examine the perceived ease of use of the system. The major viewpoint taken will be that of the users at a site, but the ability to access data at a site by a user from another site will also be examined.

FLEXIBILITY

The ability to change the definition of the CM database will be examined here. This will include the ease of adding, deleting, or modifying fields and records in the database and the impact of database changes to the various sites. It is recognized that the requirements for the CM will not remain unchanged over the life span of the Space Station. Therefore, changes to the CM software will have to be made. This criterion addresses the impact to the users of affecting the changes. Part of the impact of installing changes will be the amount of time the CM system is required to be down during installation.

1.3.2 TRADE STUDY UNIQUE

AVAILABILITY OF DATA TO OUTSIDE USERS

This will address the ease with which a user at a different location can access data from a particular site. Depending on the alternative being addressed, the data may be the actual data from the site or a summary of the data in a common format. Items considered will include the interface between sites, integration of data from different sites into reports or a central data base, and the interface with TMIS.

SECURITY

The ability of each alternative to control access to its functions and data will be addressed here. Among the items considered will be the ability to control definition (establishment) of databases and the ability to control use of the databases (especially updates) from the level of the entire database down to the field level within the database.

USER ACCEPTANCE

This will address the level of user acceptance anticipated for the alternatives. An example might be whether a particular alternative will tend to be looked on unfavorably because it mandates a set of controls that a given user group has never used in the past and does not see a good reason to use in the future. This criterion is included because a CM system which is disliked by its users stands a good chance of not being used or of being used incorrectly. Either way, the CM system will not help the users produce high quality software in a cost-efficient manner. In fact, if the user dissatisfaction is great enough, the CM system could be a contributor to lower quality and greater costs.

ADAPTABILITY

This criterion will address how well the alternatives can provide a CM system which is adaptable to the needs of its users. A system which cannot be molded to fit the user's normal procedures can cause quality and productivity problems when the users are forced to change their procedures or when they ignore or misuse the CM system so that they can continue to use their normal procedures.

1.4 APPLICABLE OPTION PAPERS

The Software Development Option Paper, Section 3.5.2, identified four tools. It is felt that more tools will become available by the time it is necessary to procure one and it is more advantageous to trade characteristics of the tools to be procured than the tools themselves.

1.5 ALTERNATIVES

1.5.1 PROVIDE SINGLE PACKAGE

This alternative would provide a single system to be used by all users. The user group with the most stringent control requirements would drive the definition of the requirements. Much consideration and coordination would have to be put into the requirements to best satisfy all the software developers.

1.5.2 PROVIDE MULTIPLE PACKAGES

This would involve analysis of user needs and the development of multiple different packages with varying level of control and variety of other characteristics. Each user group would then select the one which most nearly fit its needs, and mold his CM activities to the options provided. For the purpose of quantification in the comparison of options, the specific number of packages provided was needed. Four were selected in the belief that it would be realistic in allowing sufficient variety of characteristics.

1.5.3 PROVIDE TAILORABLE SYSTEM

This option would provide a set of table driven functions. The tables would be controlled by a 'system administrator' within the user group. The system administrator would be required to define in the tables the specific options for his user group. Some potentially tailorable items include:

- Control instrument definition
- Board approvals required
- Milestones tracked
- Software elements controlled (e.g. source code, requirements, design, users guides, etc.)
- Costing units (e.g. SLOCs, man months, memory requirements)

2.0 METHODOLOGY

In order to evaluate the alternatives presented, criteria were established against which the alternatives could be measured. The criteria used are defined in "Trade Study Criteria".

Next, in order to gain an understanding of user needs, a survey was taken of the configuration management procedures used on a number of NASA and DOD projects. Various generic documents and standards were also reviewed. A summary of the major projects included is given in "Appendix A. Survey of Configuration Management Procedures". The following projects are included in the Appendix:

SPACE SHUTTLE PRIMARY AVIONIC SOFTWARE SYSTEM (PASS) This project works for NASA's Johnson Space Center to produce the software for the Shuttle's Primary Avionics Software System (PASS). This covers three areas of responsibility, the PASS development, the support software and test tools development, and the verification of the PASS.

SPACE SHUTTLE RECONFIGURATION DATA SYSTEM This system was developed at Johnson Space Center to support the generation, maintenance, and configuration control of data used by the PASS to support the various payloads.

SPACE SHUTTLE GROUND BASED SUPPORT SYSTEM (GBS) This project is responsible for the generation and verification of the software which is executed in the Mission Control Center (MCC) and NASA's Johnson Space Center.

SPACE SHUTTLE LAUNCH PROCESSING SYSTEM (LPS) This is the software responsible for controlling the Space Shuttle countdown and launch sequence.

SPACE LABORATORY This is the project which generated the operating system for the experiment computer for the Space Laboratory at NASA's Marshall Space Flight Center.

EARTH RESOURCES BUDGET SATELLITE AND GAMMA RAY OBSERVATORY Both of these projects were done at NASA's Goddard Space Flight Center and used the same Configuration Management system.

Using the findings from the survey and an understanding of the Space Station generic requirements, the criteria list was revised and a weight proportionate to its importance to the project was assigned to each criteria. These weights are listed in Figure 2.

Each alternative was then evaluated to determine how well it would perform against the criteria. The results of this are documented in Section 3. A value was assigned to each alternative for each criteria to indicate its relative strength among the alternatives. See Figure 2. The relative strength was multiplied by the weight of the criteria and the products accumulated for each alternative to indicate the best selection among the alternatives. This is depicted in Figure 3.

3.0 RESULTS

The results of the Configuration Trade Study are summarized in Figure 2 and Figure 3. The first figure shows the criteria used, the weight assigned to each of the criterion (totals to 100), and the relative strength with which each alternative meets each criterion (also totals to 100). The second figure repeats the criteria and the weights, and replaces the the relative strengths with weighted strengths (the weight for the criterion multiplied by the relative strength of the alternative for the criterion).

As can be seen in the referenced figures, alternative 1 has its greatest strength in the areas of cost and commonality while alternative 3 is strongest in adaptability, ease of use, and user acceptance. Alternative 2 tends to share in the weaknesses of alternative 1 without any great strengths to offset those weaknesses.

The remainder of this section discusses the criteria as they apply to each of the three alternatives. Particularly emphasized are the strengths and weaknesses of each of the alternatives.

3.1 ALTERNATIVE 1 - PROVIDE A SINGLE PACKAGE

3.1.1 GENERIC

COST

For this alternative, the implementation cost would be least. However the cost of defining the requirements and getting the users to approve them would probably be more than for the other two alternatives. The cost of maintenance would be similar in that the requirements approval could be tedious, but the actual implementation cost would be less than for the other alternatives.

DEVELOPMENT TIME

Like the cost, the impact of this alternative on the development time would be in the definition of requirements. More care would have to be given to defining the specific characteristics of the system to make it palatable to all users. The actual implementation of the requirements would be less for this alternative than for the others.

TECHNICAL RISK

This alternative would involve the least technical risk to implement. There would be no new technology required over what will be required for the communication of the data among the user groups, which will also be required of the other alternatives.

IMPACT ON OTHER TOOLS

The other tools would be least affected by this alternative. Each would have a consistent interface with the CM system.

MANAGEABILITY OF DATA

This alternative would provide a consistent definition of the data maintained. However, one group may decide to apply a different interpretation

Criteria		Relative Strength		
Name	Weight	Alt. 1	Alt. 2	Alt. 3
Cost	12	50	15	35
Development Time	10	55	20	25
Technical Risk	10	40	40	20
Impact on other tools	9	50	30	20
Manageability of data	4	30	40	30
Ease of use	7	20	30	50
Flexibility	13	20	20	60
Availability of data to outside users	4	55	25	20
Security	6	25	35	40
User Acceptance	18	15	30	55
Adaptability	7	15	30	55

Figure 2. Relative Comparison of Alternatives

Criteria		Weighted Strength		
Name	Weight	Alt. 1	Alt. 2	Alt. 3
Cost	12	600	180	420
Development Time	10	550	200	250
Technical Risk	10	400	400	200
Impact on other tools	9	450	270	180
Manageability of data	4	120	160	120
Ease of use	7	140	210	350
Flexibility	13	260	260	780
Availability of data to outside users	4	220	100	80
Security	6	150	210	240
User Acceptance	18	270	540	990
Adaptability	7	105	210	385
	Total	3265	2740	3995

Figure 3. Weighted Comparison of Alternatives

to some of the data than what is intended, to compensate for the lack of flexibility in the system. This occurred in one of the projects surveyed. The project had two different groups using the same system. One group wanted to record some data not provided for in the system, so they began to use the fields in the data base that were defined for another purpose, but not used by them. This practice was done before documenting it through the requirements. Had they not updated the requirements to include the additional use, they would have run the risk of having undefined data in the data base.

EASE OF USE

The implementation of this alternative could be made as easy to use as the others, and easier to install (since there would be no decisions to be made at installation time). However, there could potentially be a learning curve for users to become accustomed to some of the characteristics which are new to them. For example, some development groups estimate cost in terms of source lines of code (SLOCs) and some use manpower (e.g. man months, weeks). Should all groups be forced to use the same units, the estimates for the groups which had to change could be inaccurate until they became accustomed to the new units.

FLEXIBILITY

This alternative would not be particularly flexible. Changes would generally require system updates, but the down time for installation would not be different than for the other alternatives. However, there could be potential problems in accessing data across user groups if one group were using a later or earlier SSE release than the others.

3.1.2 TRADE STUDY UNIQUE

AVAILABILITY OF DATA TO OUTSIDE USERS

The CM data for one user group would be the most readily available to outside users if this alternative were implemented. This is due to the fact that the data and the software to access it would be the same across all systems, and no interpretation or conversions would be required.

SECURITY

The data could be made sufficiently secure within a given user group. A subset of data from each user group would be made available to all users groups. This subset would have to be predetermined.

USER ACCEPTANCE

This alternative would probably be the least popular approach with the general users. Some of the users would feel unduly repressed by the level of control imposed on them by the system. If this were implemented, it would be difficult to encourage payload customers to use the system.

ADAPTABILITY

This alternative would not be particularly adaptable to user procedures. It would have to provide support for several procedures and methods for bypassing the ones the user did not want. If not implemented correctly, it could tend to dictate procedures. The quality of the software produced using this alternative could be adversely affected if too little control were implemented or, if too much control were implemented, productivity could be reduced.

3.2 ALTERNATIVE 2 - PROVIDE MULTIPLE PACKAGES

3.2.1 GENERIC

COST

For multiple systems, the requirements cost for the first system would be approximately the same as Alternative 1. Since the systems each have common elements that can be identified and reused, the cost of each of the remaining systems is approximately half of the cost of the first system. Both requirements and development cost follow this pattern.

DEVELOPMENT TIME

Since there will be many common, reusable elements between the systems, the development time will be considerably less than developing multiple complete systems, but will still be greater than Alternative 3. Even more time can be saved if the systems can be developed in parallel.

TECHNICAL RISK

This alternative would have more technical risk than Alternative 1 due to the multiple systems being developed, but would have less risk than Alternative 3 because each system being developed is not as complex as that alternative.

IMPACT ON OTHER TOOLS

This alternative is easy to interface with local tools because each user group will have a consistent interface with the CM system. However, there will be more local tools required in order to compensate for the differences in the multiple systems. Global tools will need to be restricted to some common set of data across the multiple systems. This data may be referenced by using a cross reference between the local name and the global name.

MANAGEABILITY OF DATA

Since each system is developed to closely meet the local user's needs, this user should have no trouble in managing data. However, the global user may have difficulty in locating data required for reports. Also, data items between systems may have different but similar meanings, making combinations for global reports more complicated.

EASE OF USE

Each system will be easy to use by the local user because it has been closely designed to meet their needs. However, the global user will have to be familiar with all systems in order to produce project level information.

FLEXIBILITY

The multiple system alternative is not flexible. Changes to each system would require system updates, but the down time would not be different than for the other alternatives. However, for multiple groups using the same system type, a potential problem exists if the user groups are using different versions of that system type.

3.2.2 TRADE STUDY UNIQUE

AVAILABILITY OF DATA TO OUTSIDE USERS

Since there will undoubtedly be differences between the systems and data names can probably not be held constant from system to system, some cross reference must be maintained for global users to use in finding data. One example of this may be in identification of change requests. CRs, PCAs, DCRs and ECRs may each be used by different systems to request software changes. Some cross reference should exist to correlate them when gathering data across systems. Also, a common set of data between systems should be defined.

SECURITY

For each system the data could be made secure within a user group. A subset of data must be made available to the global user from all systems.

USER ACCEPTANCE

This alternative will be easier to sell to the local user because it has been more closely developed to meet the local user's needs than Alternative 1. The global user may have some loss of control due to data differences between the systems.

ADAPTABILITY

Each system must be produced so that there is adequate control to ensure that the software is developed according to requirements and modifications to requirements. However, for the global user control, a minimum set of common control data should be required of all systems.

3.3 ALTERNATIVE 3 – PROVIDE A TAILORABLE SYSTEM

3.3.1 GENERIC

COST

A tailorable CM system would be more expensive to build and maintain than a single non-tailorable system since the tailoring options add complexity. However, a single tailorable system would be less expensive than four non-tailorable systems especially in the maintenance phase when the four systems began to diverge from their common base. The operations cost would be about the same as for the other alternatives. Any extra operational cost associated with a coordinator setting up the tailored system for a user group would be offset by lower costs for the general user of a system tailored to the user group.

DEVELOPMENT TIME

As with the cost, a tailorable CM system would take take longer to build than a single non-tailorable system because of the greater complexity of the tailorable system. Also, as with the cost, a tailorable system would not take quite as long to develop as several non-tailorable systems. But the difference in development time would not be as great as the difference in cost since increases in manpower would affect the required time more greatly for multiple non-tailorable systems than for a single tailorable system.

TECHNICAL RISK

The technical risk in building a tailorable CM system is greater than the risk in building non-tailorable systems due to the greater complexity of the tailorable system.

IMPACT ON OTHER TOOLS

With a tailorable CM system, local tools (i.e., those written by the user group for their use) would be easier to write and maintain since they would not have to sift through any data other than that used by and known to the local group. Global tools (those written for use by a large number of user groups; including TMIS) could be harder to implement since they could not rely on the same data being available in all user systems. To have any chance of wide use, global tools will need to be restricted to some common set of data (possibly using a cross reference between the local name and the global name).

MANAGEABILITY OF DATA

With a tailorable CM system, global management of data could become difficult since each user group's CM system might have different data in it. This could be partially avoided by forcing some subset of the data to be common to all users. Even this could be made tailorable by providing a cross reference capability to allow that data to be called by different local names, but still be retrievable from outside the user group by a common name (for example, CR,PCR,SSCR are all kinds of change requests while DR,IR,PTR are all kinds or error reports). As long as tailorability is a goal, there will always be some data which is available in some user's CM system and not in other user's CM system.

EASE OF USE

A tailorable CM system would be very easy to use by the local users - they see only the data they care about and they do not see any other group's data. That same system might be hard to use by outside users wanting to extract data from it because of the same issues discussed in "Manageability of data".

FLEXIBILITY

A tailorable CM system should by its nature not need frequent system wide changes to records and fields in its database. In addition, a tailorable system should be more likely to have design characteristics (e.g., table driven) which would make it easier to modify if its capabilities need to be expanded.

With a tailorable CM system, there would be a greater chance that different releases could be used simultaneously by different user groups. This in turn will allow system upgrades to be installed piecemeal and at the user groups' convenience, resulting in less total system down time than for a system which requires all groups to come down together for system installation.

3.3.2 TRADE STUDY UNIQUE

AVAILABILITY OF DATA TO OUTSIDE USERS

Assuming that some data is available in all user groups' instantiations of a tailorable CM system (either directly or through a cross reference) that data would be available to all users. Other data unique to a particular instantiation of the CM system might not be as easy to carry outside that version

SECURITY

With a tailorable CM system, both the level of security and the particular data items to which security applies should be selectable by the user group. This includes not only which users have access to the CM system, but also which users can update particular data items and which users can see particular data items (privacy). Because of this ability to tailor access to the database, this alternative would have the greatest security for the CM database and the data contained in it.

USER ACCEPTANCE

A tailorable CM system will be the easiest to sell to the user groups since it allows them the greatest control over their own procedures without the need for a lot of compromises to satisfy external groups. The more globally oriented groups (contract monitors, integration groups) may have a problem with some loss of control on their part. But this loss of control should be more than offset by the global groups' ability to hold the user groups more accountable for their actions (since the CM system can be tailored to match the user group's procedures, it can not be used as the scapegoat for missed schedules or poor quality).

ADAPTABILITY

A tailorable CM system would be very adaptable to user needs. Each user group should be able to tailor the system to fit their procedures and methodology for producing software. The only danger would be if the system could be tailored to have so little control that it adversely the quality of the produced software. This could be avoided by implementing the CM system to not allow tailoring outside of certain bounds or by proper management review of the options selected for an instantiation of the CM system.

4.0 CONCLUSIONS, RECOMMENDATIONS & REMAINING ISSUES

This trade study examined three alternatives for providing a Configuration Management system for the SSE.

1. Provide Single Package
2. Provide Multiple Packages
3. Provide Tailorable System.

Several existing CM systems were surveyed to establish a knowledge base for evaluating the alternatives. The results of that evaluation are discussed in "Results" and shown in Figure 2 and Figure 3.

The single system alternative would lead to the lowest cost system with the most data commonality. However, this would be achieved only after a drawn-out requirements phase, with much disagreement, and probably very little user acceptance of the final product.

The multiple system alternative has no outstanding strengths and would likely have the highest cost. The requirements and user acceptance problems of the single system alternative would be only slightly improved by the four system alternative.

A tailorable system has as its greatest strengths its flexibility, adaptability, ease of use, and expected user acceptance. The greatest weakness of this alternative is its technical risk, and this can be reduced by producing detailed plans and specifications before beginning implementation.

The conclusion of this trade study is that the tailorable system alternative is the most promising. It offers a high degree of flexibility and user acceptance with only a slight increase in cost and technical risk.

Below is a review of the issues presented in Section 1.2 and the impacts of this study on those issues.

1) Control Board Structure – A specific board structure has not been determined. Although a potential one was suggested, it is not known that it will be adopted. Nor is it known that all subsystems and customers will require the same level of configuration control. However, if the tailorable alternative is used then the board structure will not drive the software implementation of the CM system, nor will the implementation drive the board structure.

2) Customer Use of the SSE – This issue has not been resolved by the trade study. Selection of the tailorable approach optimizes the flexibility, adaptability and ease of use which would contribute to the willingness of customers to use the SSE. However, the real issue not resolved is how to determine if a customer or subsystem is autonomous. A potential approach could be addressed by static analysis routines executed against the candidate autonomous software and by validity checks within the DMS. This issue must be addressed in the future.

3) Security – No specific requirements have been defined and any of the three alternaives presented could provide adequate security. The recommended alternative represents the most likely method for accommodating the requirements when they are defined.

4) Components Managed – Any of the systems discussed must support all software components managed. As more definition of the software components is available, the SSE must address configuration control of them. New approaches will be required to support some of the emerging technologies such as relational data bases and expert systems.

5) TMIS Interface – The TMIS interface remains undefined. The CM alternative selected must address the TMIS when the interface is defined.

5.0 REFERENCES

1. Software Production Facility (SPF) Operations Planning Document, Volume VII, Book 2, SPF Level B Applications Software Requirements, prepared by IBM for Johnson Space Center, Data Systems and Analysis Directorate, Spacecraft Software Division, Systems Engineering Branch, under NAS 9-16920, February, 1984.

2. Ground Based Space Systems Programmer's Guide, Volume V: Managers and Coordinators, prepared by IBM, for Johnson Space Center, under NAS 9-14350, December, 1984.

3. Launch Processing System Configurations Management Reporting System, prepared by IBM, for Kennedy Space Center, September, 1984.

4. Spacelab Integration Configuration Management Procedures prepared by IBM, for Marshall Space Flight Center, October, 1983.

5. Configuration and Control Policies and Procedures prepared by Computer Sciences Corporation, for NASA Goddard Space Flight Center, under NAS 5-27888, December, 1984.

APPENDIX A. SURVEY OF CONFIGURATION MANAGEMENT PROCEDURES

A.1 ONBOARD SHUTTLE SOFTWARE

The Onboard Shuttle Software project is composed of three areas: the Primary Avionics Software System (PASS), the Software Production Facility (SPF) which provided all the support software, and the Independent Verification and Validation. All three areas used the same configuration management system and special provisions were made in the CM software to accommodate uniqueness.

A.1.1 TYPES OF DATA STORED

The Onboard Shuttle Software project uses two hierarchical data bases to manage its configuration. One contains the names of all systems, built or planned and data pertinent to those systems. All systems are included, whether for actual release to the field or for intermediate development. The other data base contains the control instruments and their data. The control instruments managed consist of:

CR	Change Request for FSW updates
PCR	Program Change Request for FSW updates
SSCR	Support Software Change Request for SPF updates
DR	Discrepancy Report for FSW errors
SSDR	Support Software Discrepancy Report for SPF errors
HDDR	Help Desk Discrepancy Report for commercial S/W, H/W errors
SAS	Software Approval Sheet for FSW patches

When a user creates a control instrument, he must indicate the priority, need date and project milestone driving the need (e.g., a specific flight). The system stores the date of creation, and based on the type of control instrument, the list of control boards to review the instrument. The control boards, requirements analysts, implementers and testers review the control instrument, and make assessments. The control boards assign a current disposition and if required, a target date for the next review. When the control instrument is approved, it is assigned to be built on a specific system (or set of systems). The data stored in the data base as a result of the assessment includes:

- Documents affected
- List of up to ten areas affected by the change
- The duplicate/superseding/associated control instruments
- The cost (man weeks) and target and actual completion date for requirements update
- For each error (DR, SSDR)
  - Control instrument and development phase which introduced the error
  - System in which error was identified
  - Activity which identified error (e.g. inspection, test) and which preceding activities could have identified the error
- Verification cost (man weeks) and coordinator
- CPU time and simulation time required for development and verification (itemized separately)
- List of up to five areas responsible for implementation and coordinator of each.
- Each module affected (per system) and for each module, the milestones listed in "Milestones Tracked"; names of the responsible analyst and programmer; number of source lines of code (SLOC) affected; change (in fullwords) of code, data and stack memory and accuracy of change; memory configurations affected (FSW only); manpower cost (man weeks) for analysis and implementation
- Principal Functions affected and for each, the name of the responsible analyst; the manpower to verify principal function (man weeks); and names and status of the test cases required for verification
- Date, status and destination of patches

A.1.2 TYPES OF DOCUMENTS TO BE UPDATED

A large number of FSW documents are maintained under configuration control, including the Level A requirements, Level C design, Integrated Test Plan, Test Specifications, and the Flight Computer Operating System (FCOS) Users Guide. The documents maintained for SPF include the Level B requirements, and the Level C design. The configuration control of all of these is manual. The configuration control system has had some recent upgrades which enable it to manage documents, however, none have been rehosted to the system.

A.1.3 MILESTONES TRACKED

For each scheduled release, these milestones are maintained:

- o Build target and actual date
- o Build cutoff target and actual date

For each module to be updated, the target date, revised date and status (uncomplete/complete) are maintained for the following:

- o Start work
- o Design draft
- o Design review
- o Design review complete
- o Design complete
- o Initial code complete
- o Code review complete
- o Code complete
- o Test spec complete
- o Test complete
- o Test component checkout

A.1.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

The review board hierarchy is depicted in Figure 4 and Figure 5.

A.1.5 AUTOMATIC VS. MANUAL ANALYSIS

All of the software for the On Board Shuttle project is maintained under automated configuration control. Software modules to be updated on a given build must be scheduled in the data base mentioned above. The build tools are driven by the data base and verify that all the necessary approvals have been given before the updates for a module are incorporated into the baseline. None of the documents are currently under the automated system, however, it would be possible to use the system to maintain them.

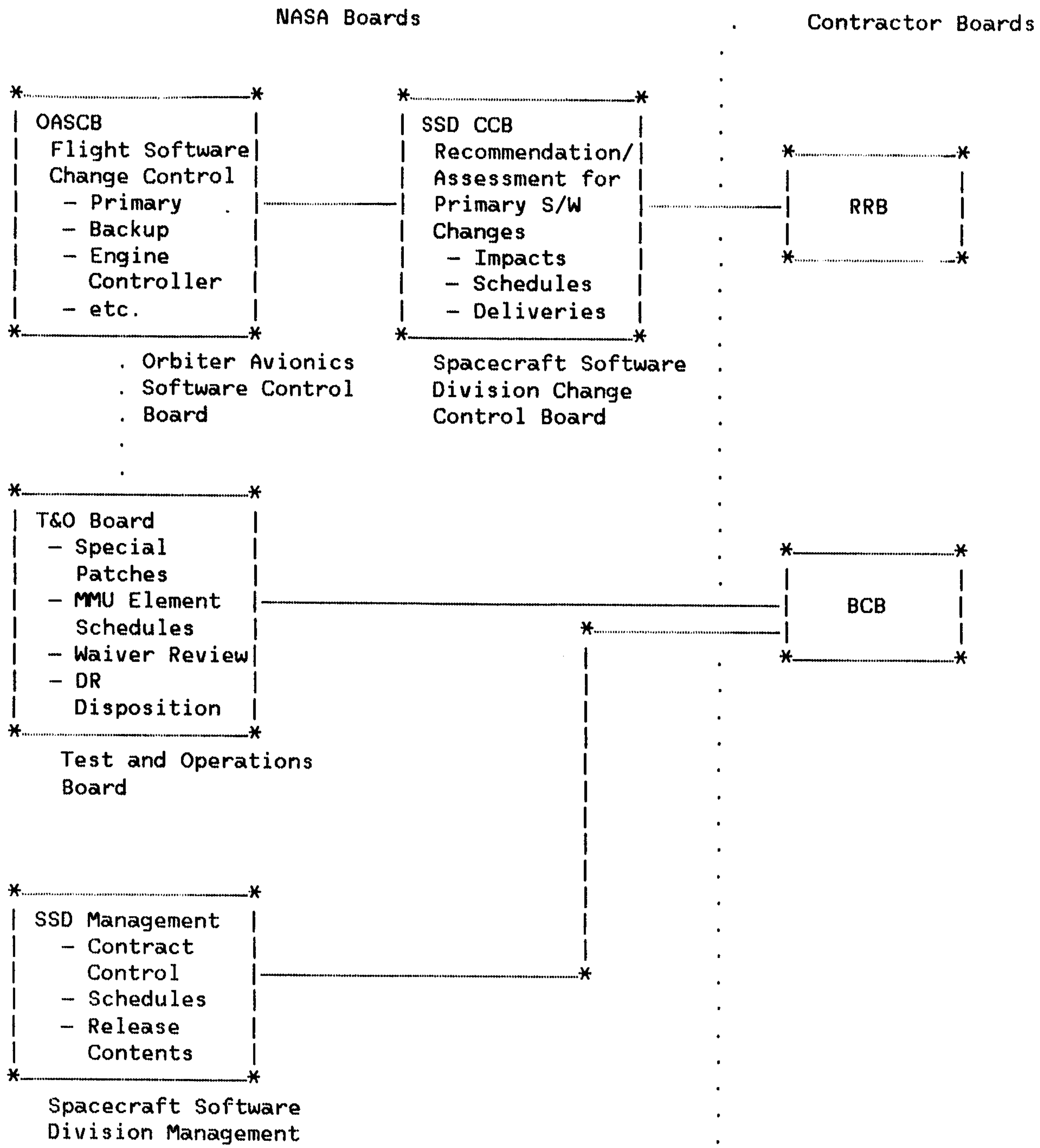

Figure 4. Onboard Shuttle Control Board Structure (NASA Boards)

A.1.6 METHOD USED FOR COSTING

Costing is done by manual estimation. As mentioned above, costs for requirements generation, development and verification are recorded in man weeks. In addition, estimation of software changes are made in source

```
NASA                          Contractor Boards
Boards     .
           .
           .  *--------------------------*   *-------------------------------*
           .  | RRB                      |   | SSRB                          |
*-------*  .  | - Flight Software Req.   |   | - Support Software            |
| SSD   |  .  |   Change Impact Assessment|  |   Change Impact Assessment    |
| CCB   |-----| - Flight Software Req.   |   | - Support Software            |
|       |  .  |   Change Scheduling      |   |   Change Scheduling           |
*-------*  .  | - Req. Issues Review     |   | - Support Software            |
           .  | - NASA Control Board     |   |   Req. Issues Review          |
           .  |   Support                |   |                               |
           .  *--------------------------*   *-------------------------------*
           .    Requirements       |                |  Support Software
           .    Review Board       *-----*   *------*  Review Board
           .                             |   |
*-------*  .                             V   V
| T&O   |  .                  *----------------------------*
| Board |---------*           | BCB                        |
|       |  .      |           | - Project Summary Schedule |
*-------*  .      *-----------| - Change Schedule Approval |
           .                  | - Discrepancy Schedule     |  Baseline
           .                  |   Approval                 |  Control
           .                  | - Build/Release Schedule   |  Board
*-------*  .      *-----------|   Approval                 |
| SSD   |  .      |           | - Interproject Technical   |
| Mgmt. |---------*           |   Issues                   |
|       |  .                  *----------------------------*
*-------*  .                             A   A
           .                             |   |
           .                       *-----*   *------*
           .                       |                |
           .  *--------------------------*   *-------------------------------*
           .  | SARB                     |   | DRB                           |
           .  | - Technical Issues Review|   | - Discrepancy Impact          |
           .  | - Architecture Analysis  |   |   Assessment                  |
           .  | - Programming Standards  |   | - Discrepancy Source/         |
           .  | - Resource Utilization   |   |   Patch Scheduling            |
           .  |   Issues                 |   | - Technical Interface to      |
           .  |                          |   |   NASA for Discrepancies      |
           .  *--------------------------*   *-------------------------------*
           .    System Architecture            DR Review Board
           .    Review Board
```

Figure 5. Onboard Shuttle Control Board Structure (Contractor Boards)

lines of code required and in change in fullwords of memory required for execution.

A.2 ONBOARD SHUTTLE RECONFIGURATION DATA

This Configuration Management System is used to control the modification of payload reconfiguration data via Data Change Request (DCR). The data is stored in units which are groups of category occurrences. A category is a template of related items and a category occurrence is one named set of data values for a given category.

A.2.1 TYPES OF DATA STORED

DCR data stored is DCR number (assigned by the system), title, description, disposition commentary, entry date/time, change date/time, originator, organization, phone, and DCR Coordinator identification.

Additional information stored is master data base of all category occurrences or mission data base of mission specific category occurrences, list of units and categories authorized for modification, and list of units and category occurrences modified.

Authorization data is stored for each user indicating categories for which data may be entered and/or whether or not the user is a DCR Coordinator.

A.2.2 TYPES OF DOCUMENTS TO BE UPDATED

There are no referenced documents managed. All DCR's and data are kept online and may be viewed at any time by anyone with access to the system. If printed documents are required, they can be printed at any time.

A.2.3 MILESTONES TRACKED

Board status of DCR is tracked as open, approved, withdrawn, or disapproved. Status of category occurrences are tracked as working or frozen (all data values within tolerances).

A.2.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

Internal review of payload data with payload supplier. DCR's are dispositioned by the Orbiter Avionics Software Control Board (OASCB).

A.2.5 AUTOMATIC VS. MANUAL ANALYSIS

DCR's are created online by anyone who has access to the system. In order to have a DCR number assigned a valid DCR Coordinator's identification must be supplied. The Configuration Management system automatically assigns the DCR numbers.

Each unit and category has valid suppliers of data assigned in the Configuration Management system. These suppliers, once a category occurrence has been modified, are the owner of that occurrence and no one else can update that occurrence until the DCR is approved and baselined.

When category occurrences are supplied, the potential supplier of category occurrences is automatically validated and if acceptable, may modify the data. After each category occurrence data is entered online, the data is automatically validated against predefined tolerances and if the data passes the tolerance tests then it is marked as a valid occurrence; otherwise, it is marked as invalid.

After all category occurrences are entered, an integration processor is run in order to validate data across category occurrences.

Once all authorized data has been entered into the system, the data occurrences are frozen by the data supplier or the DCR Coordinator which is automatically validated by the system. Only valid category occurrences can be frozen.

After all category occurrence have been frozen, then the DCR Coordinator can submit the DCR for approval through the online system.

Through the online system, the OASCB then dispositions the DCR. After dispositioning a baseline processor is initiated to make permanent updates to the system, if required.

A.2.6 METHOD USED FOR COSTING

No costing methodology is supported by this system.

A.3 KENNEDY SPACE CENTER LAUNCH PROCESSING SYSTEM (LPS)

The two components of the LPS that were surveyed were the Control Data Subsystem (CDS) and the Checkout Control and Monitor System (CCMS). The CCMS is the real time environment and distributed operating system for the LPS. The CDS is the off line system responsible for maintaining the large amounts of data required by LPS and generating executable data for the real time system.

A.3.1 TYPES OF DATA STORED

The LPS system recognized the following types of control instruments:

SPR	Software Problem Report
ESR	Engineering Support Request (user generated)
SESR	Sustaining Engineering System Improvement Requests (contractor generated)
CR/OSCR	JSC Change Request (changes to KSC S/W generated by changes at JSC)
IPR	Internal Problem Report (problems initially documented by user)

For each, the release affected, implementation phases, responsible department, affected modules, and documents affected were maintained in a data base.

A.3.2 TYPES OF DOCUMENTS TO BE UPDATED

The documents that were under configuration control were:

- Users' Guide
- Software Design Specifications
- Software Interface Document
- Programmers' Users Guide
- LPS Standards

A.3.3 MILESTONES TRACKED

Milestones were tracked at three levels: high, mid and low. At the high level, for each ESR, SESR and CR, the origination date, need date, approval date of each board, release data, validation date, and the assessment date were recorded. Release data was maintained at the mid level. Dates maintained were baseline complete, builds, integration start, validation start, and date to deliver to user. At the low level, for each module affected by a control instrument, completion dates were maintained for requirements, other documents, code and unit test. Dependencies were also recorded.

A.3.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

The control board structure used is depicted in Figure 6. The DL DED Board consisted of the NASA design group. It initially dispositions updates at a conceptual level. The ESR was a contractor technical board which reviewed control instruments, high level requirements and Engineering Assessments (ES) and recommended dispositions and implementation approaches. The Packaging meeting was attended by contractor management and systems engineers. It was at these meetings that release schedules and content were formalized and recommended to the DL DED for approval. Significant changes had to be approved by the NASA Level 3 Change Control Board. Following this, the functional groundrules and data flows were developed and presented to the Internal Contractor Panel and the NASA Design Panel for approval. After these approvals were given, the high and low level design and the error messages were generated and presented to the Internal Contractor and NASA Design Panels.

A.3.5 AUTOMATIC VS. MANUAL ANALYSIS

The software and the documents were managed by the system. Each line of software changed was associated with the authorizing control instrument. The builds were done automatically, using the stored configuration data. Regular reports were generated from the data base for tracking and status reporting. The data was also available on-line.

A.3.6 METHOD USED FOR COSTING

Change Assessments were made for each module affected by a control instrument. The units used were manweeks for software and pages for documentation. The effects of the change on CPU and disk utilization were also estimated. Engineering Assessments were maintained for each department. They were generated by accumulating the change assessments, adding overhead for engineering and management, and converting documentation costs to dollars.

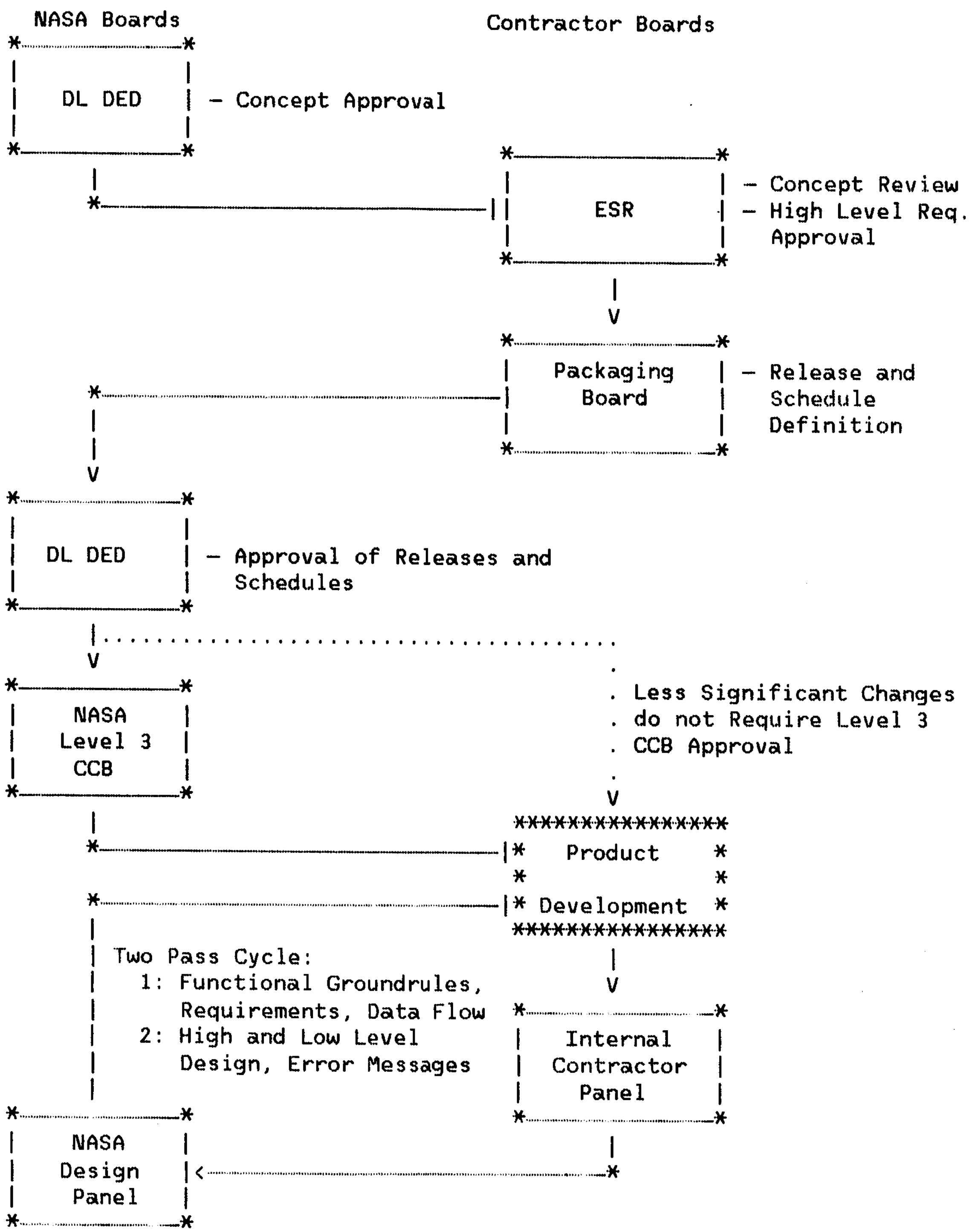

Figure 6. LPS Configuration Management Boards

A.4 SPACE LABORATORY EXPERIMENT COMPUTER

This project was responsible for generating the operating system for the experiment computer for the Space Laboratory. The work was done by a subcontractor to the prime Space Laboratory contractor.

A.4.1 TYPES OF DATA STORED

The types of control instruments maintained were:

SOFTWARE CHANGE REQUESTS (SCR) - which were initiated by the subcontractor.

SPACELAB SOFTWARE OPERATIONAL NOTES (SSON) - which document impacts and work arounds to existing SPRs.

INTERFACE REVISION NOTICES (IRN) which were initiated by the prime contractor to document changes to external interfaces.

ENGINEERING CHANGE PROPOSALS (ECP) - which are initiated by the subcontractor at the request of the contractor.

SPACELAB PROBLEM REPORTS (SPR) - which are generated by users to document problems.

If software impacts result from an IRN or an ECP, an SCR is generated. SCRs were dispositioned by the ICB and the SRB; the SSONs the SRB; the IRNs by the Contractor Control Board; the ECPs by the ICB, the Contractor Control Board and the CCB; and the SPRs by the ICB and the SRB.

A.4.2 TYPES OF DOCUMENTS TO BE UPDATED

The documents that were maintained under configuration control were the Software Requirements Document and the Level B Spec. The Level C Specs were maintained, but not under configuration control

A.4.3 MILESTONES TRACKED

The milestones that were tracked were all at the release level. They were:

- o Development release to verification
- o Verification complete
- o Delivery to KSC
- o Test complete at KSC

A.4.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

Four boards existed and not all boards were required to act on all control instrument type. The boards were:

INTERNAL CONTROL BOARD (ICB) which consisted of S/W subcontract personnel only.

CONTRACTOR CONTROL BOARD which represented the prime contractor.

SOFTWARE REVIEW BOARD (SRB) which was chaired by the software contractor and had membership from the subcontractor, NASA Program Office and Payload Office.

CHANGE CONTROL BOARD (CCB) which was chaired by the NASA Space Lab Program manager and was the highest level board.

A.4.5 AUTOMATIC VS. MANUAL ANALYSIS

The system used very little automation. Early in the project, the data was stored in a data base which had some report generation capabilities. This was discontinued later in the project.

A.4.6 METHOD USED FOR COSTING

Initial cost estimates were generated manually and expressed in manmonths for software development and pages for documentation. These costs were converted to dollars at the boards.

A.5 EARTH RESOURCES BUDGET SATELLITE AND GAMMA RAY OBSERVATORY

A.5.1 TYPES OF DATA STORED

Data stored originates from the following forms: Configuration Change Request (CCR), Component Origination Form (COF), Change Report Form (CRF), Question and Answer Form, Review Item Disposition (RID) Form, and Specification Modification Form.

The related types of data to be stored are project milestones and deliverable schedules, tests and test results, discrepancies and changes, specification modifications, questions to the requirements or development team, RID's, external data used for testing, and component development history.

A.5.2 TYPES OF DOCUMENTS TO BE UPDATED

Documents to be modified are listed on the CRF. The usual set of documents under Configuration Management are functional specifications and requirements document, preliminary and detailed design documents, system description and user's guide, test plans, and development management guide.

A.5.3 MILESTONES TRACKED

The types of milestones to be tracked by this system are milestone and deliverable dates, date of reschedule, target completion or delivery date, and responsible person.

A.5.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

The Configuration Management Board Structure is responsible for approving and monitoring all items in a project that are under configuration control (usually these are projects that are related to mission support).

There are two Configuration Control Boards: the Code 500 Board which processes Level 1 changes that have major effect on external interfaces, master schedules, or budgets and the Code 550 Board which process Level 2 & 3 changes that have less significant or no effect on schedule or budget.

A.5.5 AUTOMATIC VS. MANUAL ANALYSIS

Three types of information are Configuration Managed: documents, software, and specific types of related information. System modifications are initiated by a CCR which are followed by a CRF or COF.

Documents are manually tracked and monitored. When document changes occur, all concerned parties are informed. The primary purpose of the Configuration Management procedures is to ensure that there is a master copy of each document that reflects the current status of development and that change information is properly disseminated.

Software is configuration controlled by the use of several libraries. Each programmer has a private library containing all of the software needed to code and unit test. The software may be copied from the Controlled System Test Library (CSTL) into the private library for modification. This library is controlled by the programmer.

After unit and preliminary integration testing is successfully completed, the software moves into the Controlled Integration Library (CIL) for system integration testing with the CSTL. When system testing is completed, the CSTL is modified by the contents of the CIL.

When a build/release of the CSTL has been successfully system tested, it is copied into the Controlled Acceptance Test Library (CATL) for testing by the acceptance test team.

Finally the modified elements are copied into the Controlled Operations Library (COL) for production use.

When libraries are updated, only source code is copied and then object and executable code is generated from the copied source.

Certain specific types of related information are maintained such as developer questions.

A.5.6 METHOD USED FOR COSTING

The method used for costing is manmonths.

A.6 SPACE SHUTTLE GROUND BASED SUPPORT SYSTEM

The configuration management system studied for the Space Shuttle Ground Based Support System (GBSS) project is used to maintain the application software for that project. Similar configuration management systems used by the GBSS reconfiguration and systems support groups were not studied.

A.6.1 TYPES OF DATA STORED

Data is stored for two kinds of control instruments: Discrepancy Reports (DR) for reporting problems and documenting fixes to problems and Program Change Authorizations (PCA) for documenting other changes (upgrades) to the software. The data below is carried in the GBSS DR/PCA database. Some of the data applies to both types of control instruments and some to only one. Most of the data originates on a paper form and is transferred to the DR/PCA database.

- o Originator information (name,address,phone,organization)
- o Problem Scenario (type of activity,date/time,hardware/software configuration)
- o Problem description (symptom, impact, analysis result, and fix description)
- o Supporting data (log tapes, dump tapes, attachments, references to other DR/PCA's).
- o Affected area (department application area, and functional area)
- o Implementor (programmer initial, subcontractor ID)
- o Test case ID's
- o Documentation update status (whether or not updates are needed)
- o CSECTs updated
- o Closure code
- o Quality tracking data (software delivery on which problem introduced, type of error <data, requirements, interface,|, where it should have been found <detail design, code, IV test|, and cost to fix problem)

A.6.2 TYPES OF DOCUMENTS TO BE UPDATED

Various documents are maintained under configuration control and updates to documentation are required along with software updates. The DR/PCA database contains a flag indicating that documentation updates are required to implement the control instrument, but there is no indication of what documents are affected or when the updates are to be made.

A.6.3 MILESTONES TRACKED

The only milestones carried directly in the CM system are the target and actual dates for the control instrument to be ready for a build. Build dates and other development milestones are maintained manually outside the CM system.

A.6.4 CONFIGURATION MANAGEMENT BOARD STRUCTURE

The major controlling group in the GBSS system is the management team. Changes to the system must be approved (signed) by the manager of the person making the update. Changes requested by the customer (NASA) are documented by TIRF's (Transmittal/Information Request Forms) which are agreed to and formalized by being signed by the appropriate manager. This control is exercised without any formal board.

The Change Control Board (CCB) is made of of technical representatives from each application area. This board collects all changes to the system and ensures that they have proper management approval before allowing the updates to be submitted to the build process.

A.6.5 AUTOMATIC VS. MANUAL ANALYSIS

Control of what gets put into the system builds is done manually by management and area build input coordinators (the CCB). The system build process checks an Authorization Database built by the CCB before allowing an update to be made.

A.6.6 METHOD USED FOR COSTING

Costing is done manually. A cost for fixing problems is maintained in the CM system for use in quality measurements (the cost of making errors). This cost is maintained in manpower units (mandays, manweeks, etc.).

VIII. SOFTWARE SUPPORT ENVIRONMENT FACILITY

SOFTWARE SUPPORT ENVIRONMENT FACILITY TRADE STUDY

1.0 INTRODUCTION

1.1 BACKGROUND

The purpose of this trade study is to identify and explore factors to be considered when deciding whether the Space Station Software Support Environment (SSE) is to be centralized or distributed facility.

The scope of the SSE physically is nationwide. Special emphasis has been placed on 4 NASA centers : JSC, MSFC, GSFC, and LeRC with JSC Providing the lead role. The scope of the SSE technically is to support the complete range of software engineering functions from initial concept formulation to maintenance. Users will include commercial and academic customers building systems to checkout and control their experiments/payloads, single contractors building large computer systems such as the onboard operating system, and multiple contractors writing onboard and ground applications software.

NASA desires the SSE to be the single environment for software development on the Space Station program. This is a cost saving philosophy. It recognizes the fact that a significant cost in the development of a complex computer system is the support environment in which the system is developed. Past programs have seen each NASA center (and often individual contractors) develop individual software development environments. This duplication and the unplanned and therefore complex interfaces between the environments has impacted the cost of maintaining these programs.

Given that the SSE is common for all Space Station software development and given that this development effort will be a nationwide project, the question of facilities naturally arises. Is the facility one central NASA facility with remote workstations at each NASA and contractor site, or is the facility a network of smaller facilities at multiple sites? And if it is a network, is there justification for requiring each node to have compatible hardware? These are the questions addressed.

Several assumptions have been made and are specified here:

1. The SSE will be contracted to a single contractor. This provides NASA with a single point of contact for SSE issues. The contractor will procure the software and hardware utilizing methods he deems appropriate (e.g., subcontracts, procurement). This allows for the most cost effective SSE by maximizing exploitation of S/W and H/W commonality.

2. In the case of the common distributed option the initial SSE hardware configuration will be provided to the centers along with the SSE software system. The size of this system will be based on the centers own specification of requirements to JSC. Subsequent changes to the configuration will be under the center's control. These would be changes such as the number of DASD's, printers, CPU's, etc. These changes would have to be made within compatibility specifications which would be the responsibility of the lead center.

3. It is assumed that SSE support personnel would be provided at each major host facility.

4. Workstations for the Space Station will be powerful desk top personal computers. The goal of the SSE will be that these intelligent work stations (IWS) will be able to perform many tasks themselves and also act as a terminal to the host processor to which it is attached. Ideally the user's interface will be the same wnether on an IWS or a "dumb terminal" attached to a host.

5. The Phase B RFP stated that the onboard O/S, NOS and User Interface Language will be a part of the SSE. It is assumed these and certain other user standard utilities (e.g., Data base management system) will be provided in the SSE.

1.2 ISSUES

The following are the significant issues addressed in this trade study.

1) Procurement Process - The Phase B RFP states that the SSE contractor will procure the hardware for the SSE. However, the procurement strategy may be considerably different if the SSE is distributed among several NASA centers each using different hardware.

2) Insertion of New Technology - Ada is the suggested language for the Space Station. Yet neither Ada nor any Ada Programming Support Environments (APSEs) will be very mature when the SSE is begun. Therefore it is crucial that the SSE be designed in a way that will facilitate upgrades of compilers and APSEs. Also, powerful software engineering tools are beginning to emerge. These should be provided to the software developers as they are available.

3) Use of Intelligent Work Stations - This is the first major NASA project since the emergence of the IWS. The allocation of functions to the IWS and the interface between the IWS and host will play a vital role in the SSE.

4) Use of the SSE by Customers - It is currently unclear the extent to which NASA will encourage/require commercial or scientific customers to use the SSE. If the customers are users of the SSE then the facilities must be made available to them in an efficient manner.

1.3 TRADE STUDY CRITERIA

The criteria used in this study are divided into two groups - generic and unique. The generic criteria are Cost, Risk, Performance, Standardization/Commonality and Growth/Technology Insertion Potential. The study unique criteria are Data Base Management and Processor Management.

1.3.1 GENERIC CRITERIA

1.3.1.1 COST

Costs related to this trade study include development and operational costs for the Space Station onboard and ground data management systems and the SSE itself. Distributed or centralized facilities will also have cost differences as functions of actual computing resources, communication, physical plant, and support services costs. Several elements of the cost criteria have been identified that point out differences between the three options. These are listed below:

1. SSE procurement process - What agencies and procedures will be used to procure the initial SSE hardware and software. How will subsequent changes to the hardware and software of the SSE be handled.

2. Initial SSE S/W development costs - How will the SSE be initially developed and what cost factors will be variable.

3. SSE S/W maintenance costs - How will the SSE be maintained and what cost factors will be variable.

4. Hardware costs - What factors will affect the cost of the hardware for the various SSE facilities options.

5. System support personnel - What organization will the SSE system support organization take and how efficient and effective will it be.

6. Physical plant - How will the buildings, rooms, A/C, operations etc, to support SSE facilities affect the cost of the SSE.

7. Communications cost - How will communication costs for workstation usage and data transfer affect the cost of the SSE.

8. H/W and S/W recovery - Will the SSE design preclude the recovery of any hardware or software at the NASA sites for possible use in the SSE system.

9. Software commonality - Will the SSE foster the "software factory" atmosphere required for effective reuse of Space Station software.

10. Educational costs - How will teaching users and support personnel about the SSE affect the cost of the SSE.

1.3.1.2 RISK

The risks associated with SDE facilities lie in 2 main areas: risks associated with providing and supporting of the SSE and risks associated with the use of the SSE.

1. State of the art - What hardware and software technologies are required to develop each type of facility and how mature are they.

2. Customer/Contractor acceptance of the SSE - Is there a risk that the customer and contractors will not utilize the SSE efficiently or react negatively towards software development methodologies supported by the SSE. How will the type of facility affect this risk.

3. Control over the contractors - Will any type of facility gain NASA an advantage in the goal of trying to provide the minimum but necessary control over contractor generated software that will be developed on the SSE.

4. Control over the customer - Will any type of facility gain NASA an advantage in the goal of trying to provide the minimum but necessary control over non-autonomous customer generated software that will be developed on the SSE.

5. Backup and recovery - What backup and recovery requirements are there for the SSE and does any type of facility address this process better than the others.

6. Growth limitations - What are the chances of exceeding the limitations imposed by the SSE.

7. Maintenance skills - Because of the long duration of the Space Station program, it is likely that the life span of the SSE will be 20 to 30 years. Maintenance skills will be required to make needed software and hardware upgrades. How will the type of facility affect the availability of applicable skills.

1.3.1.3 PERFORMANCE

The performance of the SSE is a criteria with two viewpoints. One is the performance of the SSE in the task of supporting end users. The second is the performance of the SSE in supporting the task of integrating the end user's work products into their intermediate or final usable forms (i.e. a DMS memory load, a set of design documents, schedules, etc.)

USER SUPPORT - User friendliness can be addressed by providing state-of-the-art tools to aid users in each phase of the software development process, by standardizing user interface techniques across SSE tools, providing on-line user documentation, tutorials and help information and by requiring fully interactive user workstations even for remote users.

How a facility supports a user is a complex perception issue. Programmers notice response time and down time. Managers notice lack of control over a resource that is critical to their success. Initial impressions can go a long way towards user's ultimate acceptance of a system. Having a stable SSE available early on will be critical. The three different facilities options all have different effects on the following user support elements:

1. Perceived user friendliness - What factors about the three facilities options affect the views that the users have of the system.

2. User control of SSE resources - Will users feel that they have any control over the SSE resources. Can additional capabilities and capacities be requested and received in a timely manner.

3. Control over unauthorized use of the SSE - How will NASA control how the SSE is used.

4. Support for site unique uses of the SSE - Will the various NASA sites and contractors be able to use the SSE for unique applications.

5. Effectiveness of SSE support personnel - How successful will SSE support personnel be at solving user's problems.

6. On-board use of the SSE - Will the SSE be able to support onboard users.

INTEGRATION SUPPORT - The integration process occurs in all aspects of the software development effort: planning, scheduling, coding, testing, build, and release. Work products gathered in the integration activities includes programs, documentation, and status. Each step in the integration activity abstracts the input data to a higher level. The elements listed below will help determine which options facilitate the speed, ease, and effectiveness of the various integrating functions:

1. Integration testing - How well does the SSE support integrated testing at the user's site and at NASA sites.

2. Speed - How much time will be required to execute integration functions.

3. TMIS interface. - How will the SSE support the TMIS interface.

4. Communication and reviews - How well will the SSE support on-line documentation access, work product reviews, user to user communication, and standards definition and enforcement.

1.3.1.4 STANDARDIZATION/COMMONALITY

Standards and exploitation of commonality allow system designers to implement cost effective and growth oriented systems.

1. Will any SSE facility option allow greater exploitation of commonality.

2. Will standards be easier to define and enforce on any of the SSE options.

1.3.1.5 GROWTH/TECHNOLOGY INSERTION POTENTIAL

The Space Station RFP emphasizes a design philosophy which allows for stepping up to advanced technologies as they become stable. This philosophy, if adhered to, will make the management of growth of the SSE and DMS as easy as possible. In this section are the aspects of growth management that are affected by the type of SSE facility. They are:

1. Limits - Are there any limitations on the growth of processing power, data communications or software function within the SSE.

2. Technology insertion - Will the SSE design allow new technology insertion with minimum impact.

3. Upwards Compatibility - Will there be upwards compatibility of hardware and software to facilitate growth of the SSE.

4. Distributed intelligence - Will the SSE be adaptable enough to allow the integration of more and more intelligence into the environment.

1.3.2 TRADE STUDY UNIQUE CRITERIA

1.3.2.1 DATA BASE MANAGEMENT

There will be many data bases created on the SSE. There is likely to be much interaction between these data bases. Sharing and communication of data between these data bases will occur within and between centers, contractors and customers. How the type of SSE facility affects this creation, storage, and sharing of data will be important. The following list is used to determine how well each type of facility supports the data management process:

1. Data storage - How will the SSE handle data base management.

2. Data sharing/integrity - How will the SSE handling the sharing of these data bases between users. How will the SSE ensure that all copies of data are the same.

3. Security - How will the SSE ensure the security of these data bases.

4. Backup and recovery - How will the SSE provide for backup and recovery of data in the event of a minor and catastrophic failure.

1.3.2.2 PROCESSOR MANAGEMENT

The CPU will be a critical resource of the SSE. How this resource is managed by the SSE will affect the user's view of the SSE. Insufficient processor power will result in slower response time for interactive users as well as lower total throughput. Total processing power is defined by peak demand. Security and backup configurations also must be considered. The following factors are affected by the facilities options:

1. CPU contention – How will the SSE handle the distribution of users across processors in order to optimize the resource and present the fastest response time to the interactive user and also optimize total job throughput.

2. Handling peak demand – Will peak demand determine the size of the SSE.

3. Backup and recovery – Will the SSE be designed to allow backup of processing in case of failures (including catastrophic failure).

1.4 APPLICABLE OPTION PAPERS

- 1.4.2 High Order Languages
- 1.4.4 Advanced Tools
- 2.1.1 Data Base Management
- 3.5.2 Software Development
- 3.5.3 Systems Integration Test and Verification

1.5 ALTERNATIVES

Three options for facilities are presented. The first option is a centralized facility with local and remote workstation access. The second option is a group of distributed facilities with a common hardware environment and common software. The distributed facilities would again be accessed via local and remote workstations. The distributed facilities would be networked together for the necessary integration functions. This option shall be called "common distributed". The third option is a group of distributed facilities with unique hardware environments.

1.5.1 CENTRALIZED SSE

A centralized SSE would be located at the Johnson Space Center. Use of the SSE would be via workstations which could be located anywhere in the country. No limitation is set in this paper on the number or sizes of host processors which would accomplish this SSE. It is assumed that NASA would provide sufficient data communication and processing power to meet response time and throughput requirements of all users. This option is shown in Figure 1.

Because of the distributed and hierarchical structure of SSE users, it is assumed that a corresponding structure would functionally exist in a centralized SSE. That is, individual users would promote work products (software, documentation, schedules, etc) up through higher and higher levels of integration. Different levels would functionally exist as separate users but physically might reside in the same processor.

Testing of software products not designed to be executed in the SSE would either be done in the SSE via simulation or the software loads would be built in the SSE and electronically delivered to a user test set for execution in the target environment. Operational software loads would likewise be built and delivered.

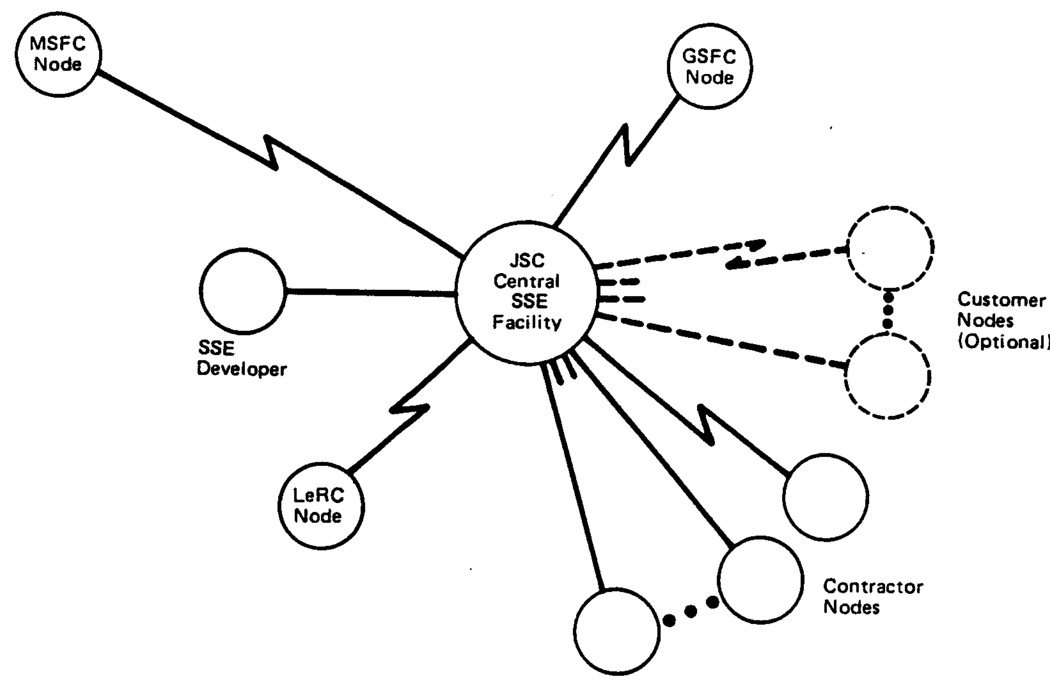

Figure 1. The SSE as a Centralized Facility

1.5.2 COMMON DISTRIBUTED SSE

Once the decision is made to have a distributed SSE, the question "how distributed?" naturally arises. This alternative provides for distribution of compatible host hardware and common software at multiple sites. The functions provided are similar to those in the central SSE option, but are augmented with communicaton functions between facilities. The lead facility would be at JSC. The user interface to the facilities will be either IWS or "dumb terminals." The number and locations of facilities will depend on the distribution of work to be done. All software and hardware will be Government Furnished Equipment (GFE). Figure 2 depicts one possible distribution.

All host processors and workstations in this option are compatible H/W systems.

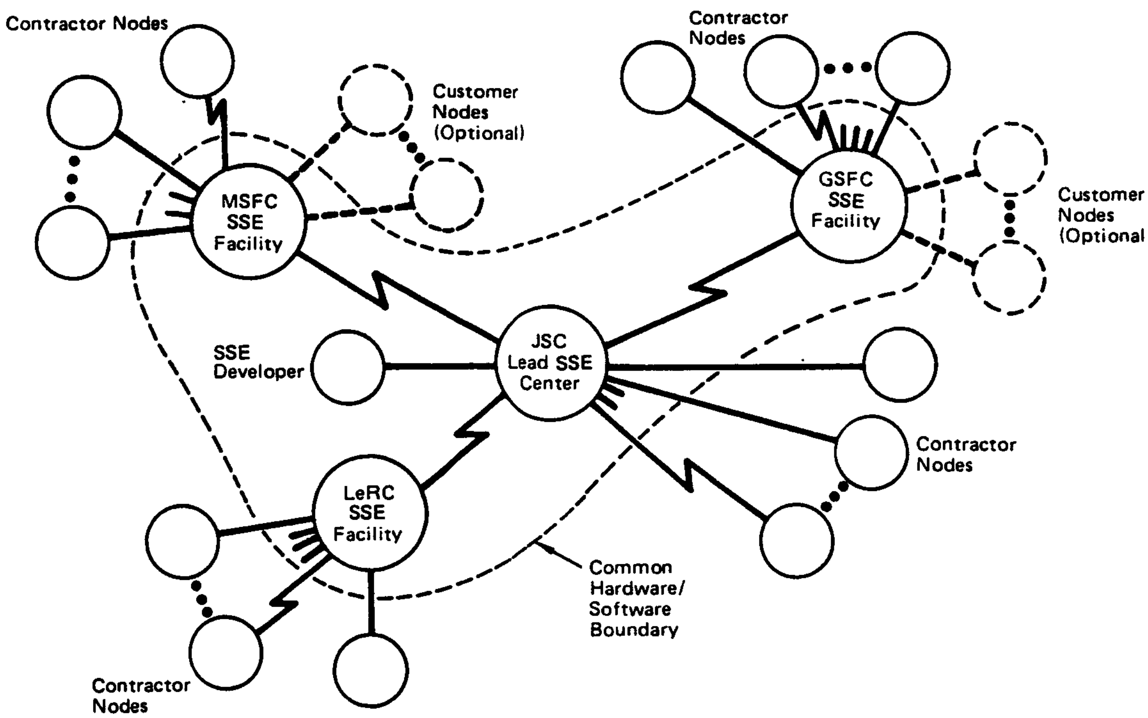

Figure 2. The SSE as a Distributed Network of Compatible Systems

1.5.3 UNIQUE DISTRIBUTED SSE

Most NASA software contractors have developed software engineering methodologies with which they are familiar and comfortable. These methodologies are often tied to a certain H/W system. The unique distributed option addresses this fact.

This option allows unique systems at each of the distributed sites within the NASA. A formal Interface Control Document (ICD) would define the interfaces (i.e., format of products delivered) between the various facilities with the lead facility at JSC.

Each facility would have the freedom to select the hardware and software products which would be most compatible with their installed base thus minimizing their individual initial cost and training requirements.

Although the hardware/software at each individual center could be different all SSE functions would be supported in a transparent manner at the program level. These functions include integration, CM, build, delivery, DMS user services, standards enforcement and integrated and system level testing.

Data maintained on these unique local facilities would not be easily interchangeable among users. Special SSE services would be provided to support this data interchange if required. The facilities would be accessed via local and remote workstations and would be networked together. This option shall be called "unique distributed".

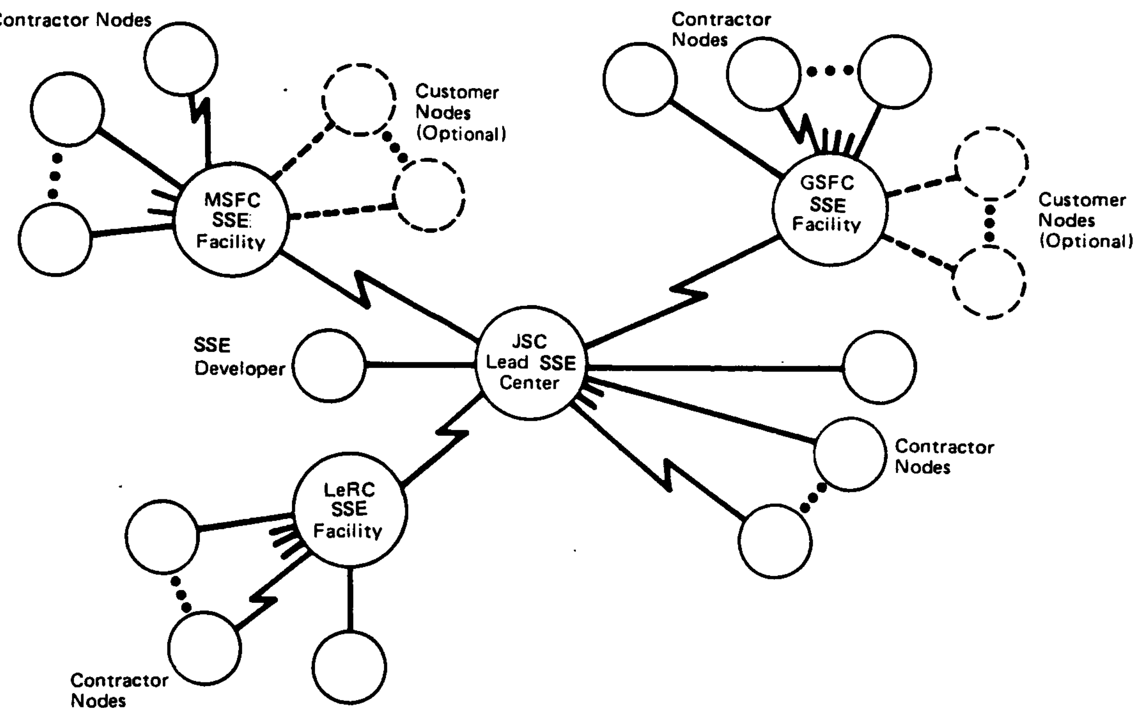

Figure 3. The SSE as a Distributed Network of Incompatible Systems

2.0 METHODOLOGY

This trade study is based on surveys of past NASA software development environments, research into the current literature, interviews with users and developers of software development environments, interviews with software development managers, interviews with large computer system engineers, and the author's experience base.

Appendix 1 contains a summary of some of these surveys.

3.0 RESULTS

3.1 COST COMPARISONS

3.1.1 CENTRALIZED SSE COST

A centralized SSE would have a centralized procurement process. This single agency would be responsible for the host computing facility. This agency would have to respond to all centers' changing requirements for SSE resources and as much as possible provide the optimum configuration at all times. This could require trading off resources among user groups taking into account various work loads and schedule constraints. This process is very susceptible to intercenter rivalries which might cloud true resource needs and result in unfair and inefficient SSE resource management.

The following areas affecting cost of the SSE would be minimized with a centralized SSE :

1. physical plant - buildings, rooms, A/C, power, etc.

2. system support personnel - operators, system engineers, help desks, etc

3. educational costs

To minimize the software development costs for Space Station, the SSE must provide an environment which supports a software factory atmosphere. The generation of reusable software components must be emphasized and supported by the SSE. A mechanism must be provided to aid the user in finding reusable software when the SSE is queried about it's existence. A centralized SSE host facility would allow a program library structure and access methods which could optimize the reuse of previously designed, coded, and tested software components. Maximizing this advantage however would required similar development methodologies and effective standards definition and enforcement across all space station software development efforts.

A disadvantage of a centralized SSE would be in the area of H/W and S/W recovery at the various NASA sites. Currently existing facilities that might be available for Space Station software development use might not be usable because of incompatibilities.

Communication costs would be higher for a centralized SSE facility, but it is not felt that this factor would be significant. Communication costs are falling and also NASA could possibly utilize some of its existing networks. Most users would require long distance access for workstation sessions but there would be no need for long distance communication during integration processes. Many advances are currently being made in the area of devices to cluster remote workstations and provide very efficient sharing of communication lines to the central facility.

There will be much use of the SSE for documentation storage. For documents that must be available at all sites such as user documentation, tutorials, and on-line HELP functions, a centralized SSE will minimize the cost for DASD to store this type of data.

3.1.2 COMMON DISTRIBUTED SSE COST

Given assumption 2 in section "Background" the initial procurement of even the common distributed SSE would be handled by a single agency thus minimizing the procurement overhead. However, total processing power required by all distributed locations might total to greater than the central SSE in order to handle peak conditions at each center separately. Costs for multiple copies of commercial software for the SSE can be minimized with commercial licensing agreements.

Greater costs would be incurred because of the multiplicity of physical plants and system support environments.

A common distributed SSE could also be designed to support the software factory environment effectively. And, there would be more of a chance for centers to reuse currently existing or newly developed hardware and software.

Most terminal usage would not require long distance costs in a common distributed SSE but integrating functions would require burst of long distance communications.

3.1.3 UNIQUE DISTRIBUTED SSE COST

The advantage of the unique distributed SSE is that each site could retain expertise and support software gained in various software development environments and methodologies. This could be an initial cost savings but is questionable on a life cycle cost basis. Ada is the proposed language for most of Space Station development efforts and the cost of multiple versions of the Ada programming support environments would outweigh benefits of using the installed hardware base. It would also complicate a software factory environment.

Another disadvantage is that several contracts would be required to develop the SSE due to the diversity of system architecture desires at each center.

If this alternative were selected, a funding reallocation would be necessary to provide funds for the support and maintenance of the local systems by the individual NASA centers.

As in the common distributed SSE option, there would also be the extra cost of maintaining multiple sets of physical plants and support environments. Educational costs would be much higher with multiple software development environments to teach. No common Space Station software development culture would be formed. This would hinder NASA's goal for the lowest possible software life cycle costs.

3.2 RISK COMPARISONS

3.2.1 CENTRALIZED SSE RISK

SSE development risk is minimized in a centralized SSE. This is a mature hardware configuration and would allow the simplest SSE software system.

There is a real risk of poor user acceptance of a centralized SSE. An efficient, standard development environment if not used effectively will not address S/W life cycle costs as predicted.

On the other hand a centralized SSE maximizes NASA control over contractors and customers.

A centralized SSE runs the risk of large numbers of users left stranded when processors go down. A catastrophic failure could mean no SSE services for a protracted time period.

3.2.2 COMMON DISTRIBUTED SSE RISK

A risk exists in designing a common distributed SSE because of the immaturity of the technology. This is not felt to be a significant risk however. Areas of immature technology are mostly limited to distributed data bases. Constraints because of these limitations would not significantly impact the design of a common distributed SSE.

The risk of user rejection of the SSE is smaller with a common distributed SSE. It is felt that the presence of local facilities will be seen as a positive effect. It will allow the user to have more control over the SSE resources.

Multiple SSE facilities will allow each NASA center effective control over their contractors and customer generated software.

A common distributed SSE has the ability to address the risk of failure of the individual SDE facilities. If deemed necessary, the overall architecture could allow facility sites to serve as backups for other facility sites.

3.2.3 UNIQUE DISTRIBUTED SSE RISK

A unique distributed SSE limits the risk of user acceptance of the SSE. With a familiar environment the user is likely to feel more comfortable. Initial software development in languages supported by the existing environments would also be more efficient. However adoption of Ada would obviate the advantage.

There is a risk in developing the interface between the various facility sites and the lead facility at JSC. It may be difficult to implement the electronic interface between incompatible hardware. (See RNET in Appendix) There is also a risk in defining an incomplete or ineffective ICD which will require modifications resulting in software impacts at the various facility sites.

The risk in a unique distributed SSE relates to the total life cycle costs associated with software built in this environment. Commonality across the project would not be exploited. Standards would not easily be applied in the different environments.

There is a risk that if the DMS user services are provided only at the integration level, users, both contractors and customers, may choose to develop unique code rather than use some of the DMS services. If this happened, it would increase cost of the program and effect the capability for technology insertion.

Unique environments would not allow for the backup facilities by facilities in other locations in the event of failures.

3.3 PERFORMANCE COMPARISONS

3.3.1 CENTRALIZED SSE PERFORMANCE

3.3.1.1 USER SUPPORT

User support is viewed from the perspective of each different type of user. Many users are day to day interactive terminal users. Many other users will utilize reports and documentation in an off-line environment. In general off-line users should be unaware of whether the SSE is centralized or distributed. On-line users can also have a transparent interface to the facilities with appropriate attention to this factor during the SSE design.

For long distance real time users to have a positive perspective of a centralized SSE, appropriate attention will have to be spent on acquiring reliable and fast communication links. This should not be a problem however.

Another important factor affecting the usability of a system is the perceived control a user has over the resource which is critical to the successful completion of his or her task. A centralized SSE may cause the feeling in users and managers of users that it will be too difficult to address problems with the resource. At one extreme, many more levels of control and therefore more justification and effort will be required to add capacity or capability to the SSE if deemed necessary by a remote site. At the other extreme, single users with daily problems may find long distance help unsatisfactory. However, by centralizing the system support activity and providing enhanced communication capabilities, a more efficient and effective system support organization might result.

A centralized SSE would minimize the ability of remote sites to make unique uses of the SSE. Site unique applications within the SSE system itself would be requested of the lead center, reviewed for true uniqueness, and eventually delivered. Site unique uses of the SSE computing hardware would not be possible. This would eliminate any "hands-on" type operations such as required in some testing situations.

A centralized SSE could support on-board use of the SSE as well as any other option.

3.3.1.2 INTEGRATION SUPPORT

A significant advantage of the SSE over software development in past NASA programs will be the ease with which the SSE will allow intercenter communication, review, requirements and interface specifications, and standards definition and enforcement. This support is optimized in a centralized SSE. Documents for communication and review are on-line and available to all users at all sites with small time delays and simple procedures necessary for routing them between centers.

The time required to execute all integrating functions would be minimized in a centralized SSE. The procedures for promoting all types of work products (i.e. programs, test cases, designs, schedules, etc.,) to higher levels for integrated activities would be simpler and faster to implement and execute in a centralized SSE.

The TMIS interface is not well understood. There are no apparent advantages in a centralized SSE to the TMIS interface other than providing one source for acquiring data that needs to be transferred to the TMIS.

3.3.2 COMMON DISTRIBUTED SSE PERFORMANCE

3.3.2.1 USER SUPPORT

A common distributed SSE probably has the best chance of optimizing both perceived and real user support. Most problems with long distance usage would not be a factor - although because of the geographical distribution of SSE users even a common distributed SSE would have many remote users.

With the SSE facility local to each site, users will have more control over the resource. More capacity could be added without intercenter justification. More capabilities could be added in two ways. First, "official" SSE capabilities would have to be requested of the lead center and delivered at a later date. Other applications, as long as they met standards, might be added by the sites for unique processing. A local SSE would allow "hands-on" operations if necessary. Systems support personnel would be closer at hand in a common distributed SSE to provide a more effective assistance function. This assumes that the support function resource is addressed properly and not diluted by the distribution of the SSE.

More effort and resources would be necessary to maintain security in a common distributed SSE. Much data would be transferred between sites. Security efforts might be less effective when handled by many agencies as opposed to just one. The advantage of allowing site unique uses of the SSE brings the disadvantage of possible unauthorized or inappropriate uses.

3.3.2.2 INTEGRATION SUPPORT

Intercenter communications and reviews (for requirements and interface specifications, standard definition and enforcement, etc) could be well supported by a common distributed SSE. The logistics and the procedures for gathering the data would be more complicated and time consuming than a centralized SSE, but still very practical considering the advantages of this type of communication.

Other integrating functions such as system builds, planning, scheduling, and configuration management would also be slower because of the gathering of data required from the remote hosts. Procedurally however, this is not a significant factor.

Support for the TMIS interface would be similar to a centralized SSE. A common distributed SSE might facilitate the TMIS interface if NASA managers at the sites require site SSE data - the data would not have to be processed through a centralized interface.

3.3.3 UNIQUE DISTRIBUTED SSE PERFORMANCE

3.3.3.1 USER SUPPORT

User support in a unique distributed SSE would appear similar to a common distributed SSE as far as availability, support and site control over the resource. However, the SSE system provided to run on the distributed facilities might be limited in function compared to a centralized SSE or common distributed SSE. A robust, project wide tool set for software development would not be attainable because of the incompatible environments of the various machines.

System support personnel at various facilities would not be able to "compare notes" and would minimize the possibility of learning from other center's experience base. Users would have to be educated both on their systems and also on any integration system that they used.

3.3.3.2 INTEGRATION SUPPORT

A unique distributed SSE would complicate the integrating functions of the SSE. This is the point where all sites have to communicate and share data and procedures. Incompatibilities in the SSE's will be a factor here and will have to be overcome during integration activities. Data bases will have to be made consistent, communication procedures will have to be designed, and data will have to be converted to similar formats. Not only will data formats be a problem but networking different systems presents significant communication problems (see RNET in appendix). These problems will cause integration functions to be harder to design and maintain.

3.4 STANDARDIZATION/COMMONALITY COMPARISONS

3.4.1 CENTRALIZED SSE STANDARDIZATION/COMMONALITY

A centralized SSE addresses both standardization and commonality well. Compatible hardware and software systems would allow for commonality of data bases, communication, development methodologies, procedures, terminology, and training across all users of the SSE. This commonality would foster creation of a Space Station software engineering culture which would enhance NASA's program management task.

3.4.2 COMMON DISTRIBUTED SSE STANDARDIZATION/COMMONALITY

A common distributed SSE has all of the advantages of standardization and commonality as described above for a centralized SSE.

3.4.3 UNIQUE DISTRIBUTED SSE STANDARDIZATION/COMMONALITY

Many advantages of commonality would be lost in a unique distributed SSE. With various software engineering methodologies in place, a common experience base of procedures, terminology, problem resolution and training would be lost. No global Space Station software engineering culture would be created. This would affect Space Station software life cycle costs by requiring operational contractors to learn multiple software development methodologies.

3.5 GROWTH/TECHNOLOGY INSERTION POTENTIAL COMPARISONS

3.5.1 CENTRALIZED SSE GROWTH/TECHNOLOGY INSERTION POTENTIAL

A centralized SSE represents a possible growth limitation problem when compared to a distributed SSE. A centralized design might become cumbersome if the number of users grows much larger than the number for which the SSE was originally designed. A important factor likely to affect this limitation is the evolution in integrated workstation products occurring now. Powerful workstations, compatible with mainframe processors, are becoming available. Response time issues can be addressed by this technology. Growth is accommodated not only by adding to the central host complex but by adding workstations. This technology will evolve the SSE from a centralized facility to a distributed one. A real danger exists then that an initial centralized philosophy for the SSE would limit the effectiveness of IWS's and local area networks of IWS's.

A centralized SSE allows SSE developers to ensure the H/W and S/W is designed for upward compatibility to allow for significant growth with minimum impact to the SSE system software.

Another advantage of a centralized SSE is that one agency would be responsible for controlling growth. This agency would have more power than multiple site oriented agencies. This agency could attempt to optimize SSE resources across all sites for the most cost effective growth management.

3.5.2 COMMON DISTRIBUTED SSE GROWTH/TECHNOLOGY INSERTION POTENTIAL

A common distributed SSE has the best chance of eliminating limits to growth. The nature of the design for a common distributed SSE would lend itself to adding or subtracting distributed host facilities with minimal impact to users and the SSE system. Existing facilities could expand processor capacities with a smaller risk of meeting some unexpected upper limit to growth. Upward compatibility of H/W and S/W here would have to be a part of the SSE design. A growth in communication rates for the distributed network would be another factor in growth management. A risk would exist here that the initial design of the common distributed SSE might not take into account all necessary data communication and growth might become difficult and expensive. A common distributed SSE implies a growth management function being performed at each site. Current technology however, supports a centralized network management function which can automatically collect information from distributed nodes to allow growth management from a central agency.

3.5.3 UNIQUE DISTRIBUTED SSE GROWTH/TECHNOLOGY INSERTION POTENTIAL

Limits to growth for the unique distributed SSE are again similar to the common distributed SSE. Growth in a unique distributed SSE is liable to impact more SSE software than in the other two options. This is because it is anticipated that more custom SSE software will be required in a unique distributed SSE to handle functions for which common or centralized SSE's might be able to use commercial software. Network management in a unique distributed SSE could not be performed by a lead host. This would impair any centralized growth management functions.

3.6 DATA BASE MANAGEMENT COMPARISONS

3.6.1 CENTRALIZED SSE DATA BASE MANAGEMENT

A centralized SSE enhances data base management throughout the SSE. All data bases would exist side by side, structured alike, thereby aiding any integration of the data from the different data bases. Security is enhanced, data does not have to leave the facility to be shared, although it still leaves the facility for user access via reports or terminal viewing. Data integrity is enhanced by the lack of duplication of data which could allow copies to get out of sync.

3.6.2 COMMON DISTRIBUTED SSE DATA BASE MANAGEMENT

A common distributed SSE enhances data base management through the use of consistent data base structures. Sharing the data is slightly more difficult than a centralized SSE but could double as a means of backup for other site's data bases. Security is a consideration since sharing data would require transmission from site to site. Currently there are no mature distributed data base management systems. Constraints on the SSE design would be required to assure this immature technology does not affect the SSE adversely. Therefore data base management in a common distributed SSE would actually be unique independent data bases at each node. Interchange of data therefore would be through custom generated procedures.

3.6.3 UNIQUE DISTRIBUTED SSE DATA MANAGEMENT

A unique distributed SSE could support data base management within each facility satisfactorily. However, sharing data and handling other sites data would require significant special processing (see RNET is appendix). Security would be affected as in a common distributed SSE.

3.7 PROCESSOR MANAGEMENT COMPARISONS

3.7.1 CENTRALIZED SSE PROCESSOR MANAGEMENT

A centralized SSE would in reality be multiple processors. CPU contention would be controlled by the SSE to present a fair response time to all users. Total processing power would be a function of peak use including all interactive users, simulations, and integrated testing.

A significant disadvantage of a centralized SSE is that if processor support is lost, all users will be left unsupported. If this loss is due to a catastrophic failure, then the SSE would not be available for a long time. This may not be acceptable with a manned Space Station to support.

3.7.2 COMMON DISTRIBUTED SSE PROCESSOR MANAGEMENT

A common distributed SSE has the advantage that not all users are on the same facility and a failure will therefore affect a smaller number of SSE users. If desired the common distributed SSE could be designed to allow sites to provide backup support for other sites in case of failures.

Total processing power in a common distributed SSE might be larger than in a centralized SSE because each site would have to be able to react to it's peak load conditions that if added to all other sites and spread out over time could be less for a centralized SSE. A common distributed SSE does not allow for "sharing" of resources. For example, if one center runs out of a resource, it may require a long time to procure more of the resource. However in a centralized SSE the resource would be shared equally with between centers until more can be procured.

3.7.3 UNIQUE DISTRIBUTED SSE PROCESSOR MANAGEMENT

A unique distributed SSE would handle processor management in much the same way as the common distributed SSE. However, the ability for one site to be used as a backup for another site would be severely limited.

4.0 CONCLUSIONS, RECOMMENDATIONS & REMAINING ISSUES

Based on the summary of advantages and disadvantages in Figure 4 the recommendation is that a distributed SSE of compatible hardware and software would be most effective at both supporting the user and providing NASA with a means to address software life cycle costs.

Workstations on the end user's desk will address his or her productivity. A small host integrating many local users at the contractor's site will support testing, communication among users, and data sharing and will allow software managers to effectively use the SSE for project management and configuration control.

Larger hosts at NASA centers will support effective NASA project management, the TMIS interface, and higher level of integration functions, system builds and deliveries.

All levels of hardware from the desk top to NASA centers should be compatible hardware systems with a user interface standardized by the SSE system which resides at each level. This hardware and software compatibility along with the design philosophy of a distributed SSE will give NASA the best control over growth, technology insertion and standards. This commonality approach will encourage the formation of a Space Station software development culture. With similar experience bases because of the common methodologies, procedures, interfaces, data bases, etc users will find it easier to communicate and work with peers, integrators, and managers. NASA will find it easier to manage the software from development through operations and maintenance.

Below is a discussion of the issues identified in Section 1.2 and how the recommended approach addresses them.

1. Procurement Process - If the common distributed alternative were selected, then each host site would be provided with its initial system. Then each site would be responsible for procuring additional hardware capacity as needed.

2. Insertion of New Technology - The adoption of the common distributed alternative would allow the SSE contractor to incorporate new software technology and distribute it in normal SSE system releases. Use of compatible hardware makes upgrades to more advanced hardware more efficient than using mixed hardware would.

3. Use of IWS - By having common software and compatible hardware, the possibility of providing a common interface to the user from both IWS and terminal is greatly enhanced. It is recognized that many IWSs are available and customers may want to interface with the hosts from a variety of IWS's. Using the common software and compabile hardware throughout the SSE will minimize the difficulty of effecting the interface.

4. Use of the SSE by customers - It is believed that selection of the common distributed alternative would not discourage customers from using the SSE. The availability of the DMS user services in the SSE will make it attractive for them to use. Selection of this alternative for the SSE for contractors should not preclude the use of a modified "common distributed" approach for customers. They could use their own environments for their development, deliver their software to a NASA site, where they would test it and then make it available for integration and delivery to the vehicle.

CRITERIA	MAX. POINTS	CENTRALIZED SSE	COMMON DISTRIBUTED SSE	UNIQUE DISTRIBUTED SSE
COST	200	200 - LIFE CYCLE COSTS	175 - LIFE CYCLE COSTS	100 - LOW INITIAL COSTS
RISK	150	150 - MATURITY	125 - MATURITY	100 - PROBLEMS WITH INCOMPATIBILITIES
PERFORMANCE	150	125 - COMMUNICATION - INTEGRATION - SUPPORT PERSONNEL	150 - USER ACCEPTANCE - COMMUNICATION - INTEGRATION - SUPPORT PERSONNEL	125 - USER ACCEPTANCE (FAMILIARITY)
STANDARDIZATION/ COMMONALITY	100	100 - DATA FORMATS - COMMUNICATION FORMATS - REUSABILITY ENVIRONMENTS	100 - DATA FORMATS - COMMUNICATION FORMATS - REUSABILITY ENVIRONMENTS	25 - USE EXISTING METHODOLOGIES
GROWTH/TECHNOLOGY INSERTION	200	150 - CENTRALIZED RESOURCE MANAGEMENT	200 - GROWTH POTENTIAL - COMPATIBLE SYSTEMS - CENTRALIZED AND LOCAL RESOURCE MANAGEMENT	75 - INCOMPATIBILITIES STRAIN RESOURCE MANAGEMENT
DATA MANAGEMENT	100	100 - COMPATIBLE DATA BASES - NO DUPLICATED DATA	90 - COMPATIBLE DATA BASES	25 - NEED CUSTOMIZED INTERFACES
PROCESSOR MANAGEMENT	100	90 - CENTRAL CONTROL	100 - BACKUP POTENTIAL	75 - USE EXISTING RESOURCES
TOTAL	1,000	915	940	525

01S/1025/2

Figure 4. Criteria summary, weight factors, and advantages

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6.0 APPENDICES

6.1 SPF

JSC's SOFTWARE PRODUCTION FACILITY (SPF) FOR SHUTTLE

The SPF is a centralized software development facility at JSC used for development, test, release, build, and CM control of Shuttle Primary Avionics Software and the SPF software and the verification testing of the Backup Flight Software (BFS). Users are local at JSC and remote at Rockwell in California for the Backup Flight Software, and remote at various other NASA centers such as KSC.

Problems with remote use of the centralized SPF have centered around a lack of common culture among the users and the difficulty of users communicating with SPF support personnel over long distances. The remoteness adds a level of complexity which increases the time needed to solve problems. Telecons have been utilized to address the problem but are impaired by the logistics of getting the right people in attendance and the time zone difference.

An important point for Space Station software development is that at least during the maturing phase of the SSE support personnel must be readily available to the end user. This can be accomplished by direct support at the remote host sites or greatly enhanced video conference capabilities (i.e. listing and dump availability). The SPF is a custom developed software development environment hosted on IBM 3033 and IBM 3084 mainframe processors. Some commercial products have been incorporated into this environment. Because of its complexity it took a significant time period to achieve maturity. During this time period, support for users was not optimum and productivity suffered. The Space Station SSE should be created using as many commercial products as possible in order to achieve maturity quickly and support user productivity.

6.2 LPS

KSC's SHUTTLE LAUNCH PROCESSING SYSTEM (LPS)

LPS has two major software development environments. Programs developed for the off-line Central Data System(CDS) are maintained on Honeywell 6600 mainframes. Programs developed for the on-line Checkout, Control and Monitor System (CCMS) are maintained in a specialized configuration of the target machine hardware - Modcomp minicomputers called the Software Development Lab (SDL). Both environments were custom generated and are centralized facilities.

The current contractor (Lockheed) is experimenting with a network of Apollo supermicros to decentralize and consolidate the two environments. User workstations and windowing are being used to greatly increase user productivity. Workstations are planned for software development, unit testing and some integration testing.

6.3 RNET

RECONFIGURATION NETWORK (RNET)

The RNET project is addressing a problem that NASA has with the Shuttle program because of the multiple incompatible software development environments which were used to develop major Shuttle software subsystems. The incompatibility of data bases and communication protocols between these systems presents a severe hindrance to Shuttle software maintenance in the operational era.

Twenty reconfiguration products such as the mass memory load tape have been defined as candidates for automatic transfer among the SPF, MCC, KSC CDS, and SRS. Problems being encountered include a lack of true cross vendor communication packages and the customized processes needed at each node to handle the data being automatically delivered.

These experiences support the arguments in this trade study for the SSE being a system of compatible hardware and software systems.